ADULT AND JUVENILE FISH POPULATIONS
NEAR THE D. C. COOK NUCLEAR POWER PLANT
SOUTHEASTERN LAKE MICHIGAN
DURING PREOPERATIONAL (1973-74) AND OPERATIONAL (1975-79) YEARS

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INTRODUCTION

Fish populations in Lake Michigan have undergone dramatic changes since the 1900s (Smith 1972, Christie 1974). Overfishing, sea lamprey predation, destruction of wetlands and river spawning sites, eutrophication, and contaminants have all contributed to the present state of fish populations in Lake Michigan (Wells and McLain 1973). The present fish species in Lake Michigan continue to be impacted by man, including nutrient and contaminant inputs to the lake, overfishing, shoreline modifications, invasions of introduced fish species, river modifications (dams, channelization, construction), water level changes, and power plants. It is with this latter impact that this report is concerned. Because they draw large quantities of inshore water, power plants can possibly affect many species which reside or migrate inshore. Potential operational impacts come under three categories: entrainment, impingement, and thermal effects. The data on entrainment of larval fish appear in a separate report (Perrone et al. 1983) and cover the years 1973-1979. Impingement data, also from 1973-1979, are discussed by Thurber and Jude (1984). In this report, we discuss the effects of the D. C. Cook Nuclear Power Plant on the juvenile and adult fish as evidenced from field catches. As part of our efforts to characterize the inshore fish populations and determine any possible effects of the plant on them, we seined, gillnetted, and trawled fish from the area on a regular basis from 1973 to 1979. Preoperational data were collected during 1973-1974; Unit 1 of the power plant began operation in 1975, Unit 2 in 1978. We have concentrated on presenting data analyses which bear on any potential impact of the plant. We have accomplished this primarily by statistically comparing catches at the Cook Plant

with catches at Warren Dunes, our reference station. Any significant declines in catch during operational years at the Cook Plant, but not at Warren Dunes, would be interpreted as a detrimental effect of the plant. Such a decline at Cook Plant stations could be caused by impingement at the plant or some characteristic of the plant or its operation (currents, thermal plume, noise, riprap, etc.) which repels species. Species may also be attracted to the plant area. The converse must also be considered, that species may be attracted to the Warren Dunes site. We sampled during the day and night so that diurnal activity and inshore and offshore migrations could be documented.

Lastly, biology of abundant and common species is presented. Data on spawning times, growth, disease and parasitism, spatial and temporal distribution, temperature-catch relationships, and sizes of fish present in the area are presented. These data are necessary to establish the fish community that is present and the behavior of various species in the vicinity of the plant. This information then can be used to get a holistic view of the plant and surrounding waters and how, when, and with which species and size of fish the plant interacts. Knowledge of spawning times helps with interpretation of entrainment data. Notes on diel, seasonal, and vertical movements of juveniles and adults can assist with explanation of impingement events. Species which are susceptible to impingement and those which are seldom impinged can be judged from intimate knowledge of the species and their abundance in the vicinity of the plant. We will establish the spatial and temporal variability observed in catches over the 7 years and document the patterns of spawning, inshore and offshore movements, seasonal migrations, nursery areas, effect of physical factors such as water temperature and upwelling on fish behavior, and some annual growth patterns and food consumed by abundant species of fish.

Common species will be discussed in a general manner with efforts directed at seasonal distribution patterns, sizes collected, and any atypical behavior or presence especially if related to the power plant.

MATERIALS AND METHODS

SAMPLING PROCEDURES

Details on methodology were presented by Jude et al. (1979) and only a brief description is given here. Seven sampling stations (A, B, C, D, F, G, and H) were established in southeastern Lake Michigan off the Cook Plant (experimental area) and off Warren Dunes State Park (reference area) where adult and juvenile fish were sampled (Fig. 1). Routine samples taken at these stations are referred to in this report as the standard series. Fish at beach stations A, B, and F were sampled with a 38-m x 1.8-m bag seine of 0.64-cm square mesh. Fish at 6-m-deep stations C and G and 9-m-deep stations D and H were sampled with a 4.9-m bottom trawl of 3.8-cm square mesh and 160-m x 1.8-m bottom gill nets consisting of 12 mesh sizes from 1.3 cm to 10 cm square mesh. Two stations (R and Q, respectively, at 6- and 9-m depths) were also established in 1975, north of the plant's underwater structures, and fish were sampled by trawl at station R and by gill net at both stations. Fish were sampled during the day and at night approximately once per month at each station.

Yearly standard series fishing effort was approximately equal between April and October (Table 1). Some sampling also occurred in colder months; however, monthly effort was too sporadic and catches too small to be used in statistical analyses.

Physical and limnological measurements were taken when sampling occurred in 1975-1979 and data are presented in Appendices 1-3. Similar data for 1973 were presented by Jude et al. (1975) and 1974 data by Jude et al. (1979).

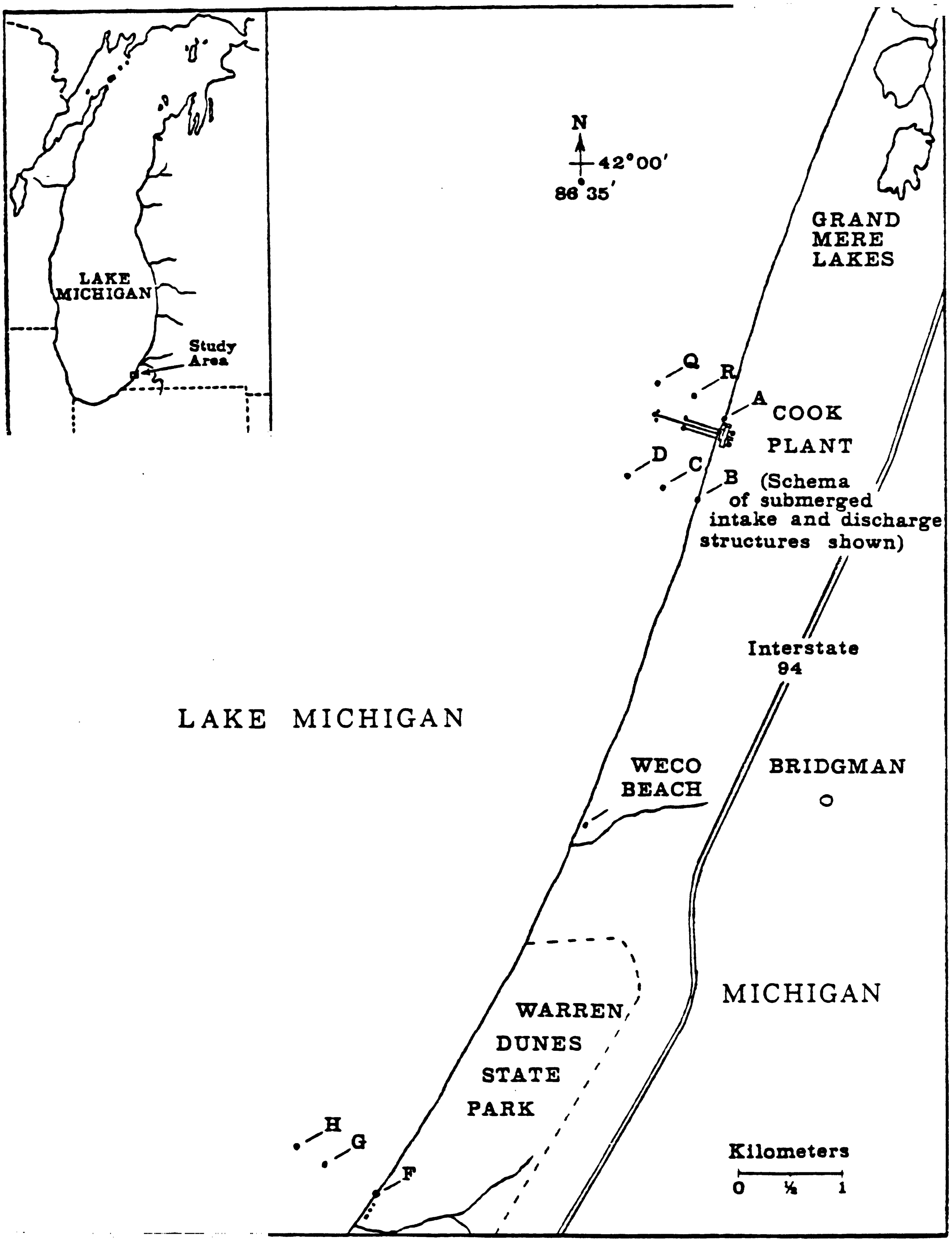


Fig. 1. Location of sampling stations at the Cook Plant and Warren Dunes study areas, southeastern Lake Michigan.

Table 1. Number of standard series nets fished at Cook Plant study areas, southeastern Lake Michigan, 1973-1979. A complete monthly series consisted of 16 trawl tows (T), 8 gill net sets (G), and 12 beach seine hauls (S).

Year	Method	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1973	T	0	0	0	15	16	16	16	16	15	16	0	0	110
	G	0	2	8	8	8	8	8	8	8	8	6	1	73
	S	0	4	7	12	12	12	11	12	12	12	10	0	104
1974	T	0	0	0	16	16	16	16	16	16	16	8	0	120
	G	2	0	8	8	8	8	8	8	8	8	8	8	82
	S	3	0	12	12	12	12	12	12	12	12	12	0	111
1975	T	0	0	0	16	16	16	16	16	16	16	12	12	136
	G	6	0	6	8	8	8	8	8	8	8	8	4	80
	S	0	0	0	12	12	12	12	12	12	12	12	0	96
1976	T	0	0	0	16	16	16	16	16	16	16	8	0	120
	G	0	4	2	8	8	8	8	8	8	4	0	0	58
	S	0	8	0	12	12	12	12	12	12	12	12	0	104
1977	T	0	0	0	16	16	16	16	16	16	16	16	0	128
	G	0	0	4	8	8	8	8	8	8	8	8	4	72
	S	0	0	0	12	12	12	12	12	12	12	12	0	96
1978	T	0	0	0	16	16	16	16	16	16	16	16	0	128
	G	0	0	0	8	8	8	8	8	8	8	8	0	64
	S	0	0	0	12	12	12	12	12	12	12	12	0	96
1979	T	0	0	0	16	16	16	16	16	16	16	16	0	128
	G	0	0	0	8	8	8	8	8	8	8	8	0	64
	S	0	0	0	12	12	12	12	12	12	12	12	0	96

References to fish are by common name (Table 2). Common and scientific names are according to Robins et al. (1980).

STATISTICAL PROCEDURES

Log-transformed, log(catch + 1), catch-per-unit-effort data for alewife, rainbow smelt, spottail shiner, trout-perch, and yellow perch were analyzed using a Model I, full factorial, balanced analysis of variance (ANOVA). Catch-per-unit-effort, an index of fish abundance, is a standard measure of catch for each type of fishing gear. One unit of effort was defined arbitrarily as a 12-h gill net set, a 10-min trawl tow, or a 61-m seine haul. Because each gear has its own unique biases, data from different gear were not combined.

Factors of ANOVA designs were dependent on the type of gear, species, and stations involved. Generally, three temporal factors were included in the ANOVA model: Year, Month, and Time of Day. The factor Year was used to explore long-term variations in fish catch with particular consideration to comparison of preoperational and operational catches. The factors Month and Time of Day were used to account for seasonal and diel fluctuations of fish movement in and out of the sampling areas. Spatial factors, Station, Area, and Depth, were employed to separate plant effects from inherent variation of fish populations. Area or Station allows comparison of a treatment area (Cook Plant) with a reference area (Warren Dunes). Stations at 6- and 9-m depths (stations R and Q) on the northern side of the plant were added in 1975 to ensure sampling in or near the thermal plume; catches from these stations were included in analysis of 1975-1979 trawl and gill net data.

Table 2. Common and scientific names of fish species collected from Cook Plant study areas, southeastern Lake Michigan, 1973-1979.

Common name	Scientific name
Alewife	*Alosa pseudoharengus*
Black bullhead	*Ictalurus melas*
Black crappie	*Pomoxis nigromaculatus*
Bloater	*Coregonus hoyi*
Bluegill	*Lepomis macrochirus*
Bluntnose minnow	*Pimephales notatus*
Brook silverside	*Labidesthes sicculus*
Brown trout	*Salmo trutta*
Burbot	*Lota lota*
Central mudminnow	*Umbra limi*
Channel catfish	*Ictalurus punctatus*
Chinook salmon	*Oncorhynchus tshawytscha*
Coho salmon	*Oncorhynchus kisutch*
Common carp	*Cyprinus carpio*
Emerald shiner	*Notropis atherinoides*
Fathead minnow	*Pimephales promelas*
Freshwater drum	*Aplodinotus grunniens*
Gizzard shad	*Dorosoma cepedianum*
Golden redhorse	*Moxostoma erythrurum*
Golden shiner	*Notemigonus crysoleucas*
Green sunfish	*Lepomis cyanellus*
Johnny darter	*Etheostoma nigrum*
Lake chub	*Couesius plumbeus*
Lake herring	*Coregonus artedii*
Lake sturgeon	*Acipenser fulvescens*
Lake trout	*Salvelinus namaycush*
Lake whitefish	*Coregonus clupeaformis*
Largemouth bass	*Micropterus salmoides*

Table 2. Continued.

Common name	Scientific name
Logperch	Percina caprodes
Longnose dace	Rhinichthys cataractae
Longnose sucker	Catostomus catostomus
Mottled sculpin	Cottus bairdi
Ninespine stickleback	Pungitius pungitius
Northern pike	Esox lucius
Pumpkinseed	Lepomis gibbosus
Quillback	Carpiodes cyprinus
Rainbow smelt	Osmerus mordax
Rainbow trout	Salmo gairdneri
Rock bass	Ambloplites rupestris
Round whitefish	Prosopium cylindraceum
Sand shiner	Notropis stramineus
Shorthead redhorse	Moxostoma macrolepidotum
Silver redhorse	Moxostoma anisurum
Slimy sculpin	Cottus cognatus
Smallmouth bass	Micropterus dolomieui
Spotfin shiner	Notropis spilopterus
Spottail shiner	Notropis hudsonius
Trout-perch	Percopsis omiscomaycus
Walleye	Stizostedion vitreum vitreum
White sucker	Catostomus commersoni
Yellow perch	Perca flavescens

ANOVA calculations were completed using the BMD8V program provided by the Statistical Research Laboratory of The University of Michigan (Statistical Research Laboratory 1975). Where designs were unbalanced due to missing samples, output from the BMD8V program was modified to provide an unweighted means analysis for unbalanced data (Fox 1973). Missing samples were replaced by the cell mean. Unweighted means analysis involves multiplying mean squares by the ratio of harmonic mean cell size to maximum cell size and subtracting the number of missing observations from error degrees of freedom.

Gill net data did not include replicate sampling, depriving the model of a specific term for within-cell error. The highest-order interaction term was assumed to be nonsignificant and its mean square represented mean square error (MSE) for all gill net ANOVAs. This procedure, based on examination of 1973-1979 gill net data, appeared appropriate except for rainbow smelt data. In this case, the highest-order interaction mean square was much larger than many of the other interaction mean squares, indicating that the highest-order interaction mean square was a poor estimate of MSE.

Distributional properties of 1973-1979 data indicated the need for transforming the data before analysis. The log(catch + 1) transformation was used to correct for positively skewed distributions (Tables 3 and 4) with treatment means proportional to the standard deviation. After the transformation, skewness was nearly zero. Elimination of months in which no fish of a certain species were caught reduced the percentage of zero catches in the analyses. High values of coefficient of dispersion indicated contagious distributions (Sokal and Rohlf 1969), characteristic of sampled organisms distributed in scattered groups.

Table 3. Distributional properties of 1973-1979 sample data for the five most abundant fish species caught in standard series trawls, gills nets, and seines at Cook Plant study areas, southeastern Lake Michigan. Coef. = coefficient.

Species	Months	Sample size	Mean catch	Standard deviation	Coef. of variation	Coef. of dispersion	Percent zero data	Kurtosis	Skewness
				Trawl					
Alewife	Apr-Oct	784*	72.7	233.2	320.7	747.8	27.9	111.0	8.7
Rainbow smelt	Apr-Oct	784*	46.1	132.2	286.4	378.5	24.6	44.7	6.1
Spottail shiner	Apr-Oct	784*	41.0	85.1	207.6	176.9	21.0	32.6	4.7
Trout-perch	Jun-Oct	560#	23.9	51.2	214.1	109.5	25.5	39.8	5.5
Yellow perch	Jun-Oct	560#	12.4	25.3	203.1	51.3	30.9	27.0	4.4
				Gill net					
Alewife	Apr-Sep	336	101.0	166.9	165.2	275.7	10.1	11.5	2.9
Rainbow smelt	Apr-May	112	6.1	13.0	214.5	27.8	30.4	27.9	4.7
Spottail shiner	Apr-Sep	336	39.7	87.4	219.9	192.2	20.8	28.7	4.8
Trout-perch	Jun-Sep	140**	5.6	10.5	186.4	19.6	22.1	24.8	4.5
Yellow perch	May-Sep	224	30.1	34.3	113.8	39.0	6.7	3.0	1.7
				Seine					
Alewife	Apr-Oct	588#	900.4	3,655.0	405.9	14,836.9	26.2	66.2	7.5
Rainbow smelt	Apr-May	168	21.5	82.6	383.6	316.9	51.2	38.6	6.0
Spottail shiner	Apr-Oct	588#	198.2	602.9	304.2	1,833.8	14.1	44.7	6.1
Trout-perch	Apr-Oct	294**	2.2	4.7	217.8	10.3	57.2	22.8	4.1
Yellow perch	Jun-Aug	252#	33.4	84.3	252.5	213.0	39.3	21.4	4.3

* Cell mean (replicate) values substituted for two missing observations.
# Cell mean (replicate) value substituted for one missing observation.
** Night catches only.

Table 4. Distributional properties of 1975-1979 sample data for the five most abundant fish species caught in standard series and station R trawls and standard series gill nets and stations R and Q gill nets at Cook Plant study areas, southeastern Lake Michigan. Coef. = coefficient.

Species	Months	Sample size	Mean catch	Standard deviation	Coef. of variation	Coef. of dispersion	Percent zero data	Kurtosis	Skewness
				Trawl					
Alewife	Apr-Oct	700	54.2	208.5	384.6	801.9	33.3	187.0	11.8
Rainbow smelt	Apr-Oct	700	30.2	76.3	252.7	192.9	31.6	38.9	5.4
Spottail shiner	Apr-Oct	700	47.4	96.6	203.7	196.7	22.0	23.4	4.1
Trout-perch	Jun-Oct	500	22.6	48.5	214.8	104.2	29.6	46.1	5.7
Yellow perch	Jun-Oct	500	11.8	25.1	212.2	53.2	30.6	30.9	4.8
				Gill net					
Alewife	Apr-Sep	360	64.9	113.4	174.9	198.4	11.7	15.7	3.3
Rainbow smelt	Apr-May	120	3.6	6.2	173.6	10.8	32.5	17.9	3.7
Spottail shiner	Apr-Sep	360	29.8	74.3	249.3	185.2	22.5	40.8	5.9
Trout-perch*	May-Sep	150	3.8	5.0	129.4	6.4	26.7	3.7	1.9
Yellow perch	Jun-Sep	240	30.2	32.4	107.1	34.7	3.8	3.1	1.6

* Night catches only.

The assumptions required in ANOVA are that experimental errors are independently and normally distributed with a common variance. Residual analyses were conducted on trawl and seine ANOVAs; transformed gill net data, which included only one observation per cell, were treated differently. Transformed gill net data, instead of residuals, were critically examined for violations of the assumption.

The assumption of normally distributed residuals was evaluated by: (1) shape of normal-probability plots, (2) Lilliefors test, and (3) histograms of levels of main factors. Results of Lilliefors test indicated that ANOVA residuals were not from a normally distributed population (Table 5). The distribution of data can depart from normality in terms of either skewness or kurtosis. Departure from normality in a fixed-effects model is not of concern if levels of a factor are homogeneous in form, that is, if the shape of the distribution of residuals is similar across all levels of the model factors (Kirk 1968). Examination of normal-probability plots and histograms revealed residuals of virtually all species at all levels of each factor of trawl ANOVAs were leptokurtic and not skewed. Seine catch residuals for all species showed the same trends, residuals of each level of main factors were leptokurtic and not skewed. Gill net transformed data varied, but within each level, distributions were similar. Distributions by levels of month for yellow perch were not homogeneous in shape. July data were platykurtic, while the August distribution was leptokurtic. These differences, however, should not affect the interpretation of ANOVA results in terms of potential plant effects.

Homoscedasticity was evaluated by examining plots of residuals against cell means and plots of residuals partitioned by levels of main factors. Examination of plots revealed that cell means were not correlated with variance and variances were similar over each level of a main factor. In a balanced design as used in our study, the F-distribution is robust with respect to departures from the assumption of homogeneity of variances. Other statistical tests for homogeneity of variance were not used because all are sensitive to departures from normality.

Table 5. Lilliefors test statistics for normality of residuals from log-transformed catch data for the five most abundant fish species caught at Cook Plant study areas, southeastern Lake Michigan. Residuals were from a normally distributed population if the test statistic (D) was less than the Lillesfors critical difference (D_c) at alpha = 0.01.

Years	Species	Months	Sample size	D_c	D
		Trawl			
1973-79	Alewife	Apr-Oct	784	0.03682	0.11097
	Rainbow smelt	Apr-Oct	784	0.03682	0.11224
	Spottail shiner	Apr-Oct	784	0.03682	0.10332
	Trout-perch	Jun-Oct	560	0.04357	0.12143
	Yellow perch	Jun-Oct	560	0.04357	0.12143
1975-79	Alewife	Apr-Oct	700	0.03897	0.13429
	Rainbow smelt	Apr-Oct	700	0.03897	0.14000
	Spottail shiner	Apr-Oct	700	0.03897	0.10286
	Trout-perch	Jun-Oct	500	0.04611	0.14600
	Yellow perch	Jun-Oct	500	0.04611	0.12400
		Gill net			
1973-79	Alewife	Apr-Sep	336	0.05625	0.07682
	Spottail shiner	Apr-Sep	336	0.05625	0.12102
	Trout-perch	May-Sep	140	0.08714	0.13137
	Yellow perch	Jun-Sep	224	0.06888	0.08443
1975-79	Alewife	Apr-Sep	360	0.05434	0.07655
	Spottail shiner	Apr-Sep	360	0.05434	0.13116
	Trout-perch	May-Sep	150	0.08418	0.15955
	Yellow perch	Jun-Sep	240	0.06655	0.09852
		Seine			
1973-79	Alewife	Apr-Oct	588	0.04252	0.11224
	Rainbow smelt	Apr-May	168	0.07954	0.21429
	Spottail shiner	Apr-Oct	588	0.04252	0.08500
	Trout-perch	Apr-Oct	294	0.06013	0.26190
	Yellow perch	Jun-Aug	252	0.06495	0.18651

Independence between replicates within ANOVA was examined by partitioning sample data by species and levels of main factors and applying the Sign test (two-tailed, alpha = 0.05 or 0.01) (Conover 1971). Under the null hypothesis, the number of times the catch of the first trawl tow or seine haul exceeds the catch of the second trawl tow or seine haul is equal to the number of times the second exceeds the first. When the null hypothesis is true, 5% of the tests should be rejected at alpha = 0.05, and 1% should be rejected at alpha = 0.01. Spottail shiner data partitioned by levels of main factors revealed a higher tendency to reject the null hypothesis than expected (Table 6). Examination of rejected tests revealed a tendency for higher catches of spottail shiners in the first trawl tow compared to the second tow at station R (6 m, north Cook). No other species or gear exhibited strong tendencies, at alpha = 0.01, for one replicate catch to exceed the other.

Factorial ANOVA allows independent tests of interaction effects as well as main effects. If all interaction effects are nonsignificant, the ANOVA describes an additive model. Each main effect may be interpreted independently of effects due to other main factors, resulting in a simple and concise description of the model. The term additivity is applicable when the total effect on each cell of the ANOVA is simply the sum of the grand mean and all the main effects of the cell.

Many higher-order interaction terms in the ANOVAs were significant ($P<0.01$). Significant higher-order interactions increase the complexity of interpreting results. Each main factor involved in significant interactions should be discussed with reference to specific levels of other factors included in the interaction term.

Table 6. Results of the Sign test (two-tailed) applied to 1973-1979 catch data partitioned by level of each factor of the ANOVA. Fish were trawled or seined from Cook Plant study areas, southeastern Lake Michigan. a = alpha.

Species	Number of tests	Number of tests rejected at a = 0.05	Number of tests rejected at a = 0.01	Percent rejected at a = 0.05	Percent rejected at a = 0.01
		Trawl			
Alewife	18	1	0	5.55	0.00
Rainbow smelt	18	1	0	5.55	0.00
Spottail shiner	23	4	3	17.39	13.04
Trout-perch	18	0	0	0.00	0.00
Yellow perch	18	1	0	5.55	0.00
Total	95	7	3	7.37	3.16
		Seine			
Alewife	13	2	0	15.38	0.00
Rainbow smelt	13	1	1	23.08	0.00
Spottail shiner	13	3	0	7.69	7.69
Trout-perch	13	0	0	0.00	0.00
Yellow perch	13	1	0	7.69	0.00
Total	65	7	1	10.77	1.54

Given that ANOVA meets parametric assumption, power analysis estimates the ability of ANOVA to detect true changes in fish abundance. Values of the least detectable true change (LDTC) in log-transformed data were calculated (for details see Jude et al. 1979). Values of LDTC were transformed to least detectable true ratios (LDTR) to express power calculations in terms of numbers of fish (geometric means of catch plus one). The LDTR is the minimum ratio between geometric mean levels that can be detected by ANOVA. Values are presented as functions of alpha and power, for two distinct sets of comparisons (Tables 7-11). Comparison of 1-yr preoperational data to 1-yr operational data at a single station or area represents a "worst case"

Table 7. Least detectable true ratios (LDTR) in geometric mean abundance of the five most abundant fish species caught in standard series trawls at Cook Plant study areas, southeastern Lake Michigan, 1973-1979. Values are given as functions of type I error (alpha = a) and power. Comparisons are of 1-yr preoperational sampling to 1-yr operational sampling and 2-yr preoperational sampling to 2-yr operational sampling at one area. Each LDTR is expressed as the ratio of the operational value to the preoperational value of the quantity "mean number per trawl tow plus one." n = sample size; MSE = mean square error of ANOVA; df = degrees of freedom of MSE.

			2-yr sampling			4-yr sampling		
				Power			Power	
MSE	df	a	n	0.90	0.95	n	0.90	0.95
			Alewife					
0.1502	390	0.01	56	1.92	2.04	112	1.58	1.65
		0.02		1.84	1.95		1.54	1.61
		0.05		1.73	1.84		1.47	1.54
		0.10		1.64	1.74		1.42	1.48
			Rainbow smelt					
0.0660	390	0.01	56	1.54	1.60	112	1.36	1.40
		0.02		1.50	1.56		1.33	1.37
		0.05		1.44	1.50		1.29	1.33
		0.10		1.39	1.44		1.26	1.30
			Spottail shiner					
0.0520	390	0.01	56	1.47	1.52	112	1.31	1.34
		0.02		1.43	1.48		1.29	1.32
		0.05		1.38	1.43		1.26	1.29
		0.10		1.34	1.39		1.23	1.26
			Trout-perch					
0.0576	279	0.01	40	1.61	1.68	80	1.40	1.45
		0.02		1.56	1.63		1.37	1.41
		0.05		1.49	1.56		1.33	1.37
		0.10		1.44	1.50		1.29	1.33
			Yellow perch					
0.1067	279	0.01	40	1.91	2.03	80	1.58	1.65
		0.02		1.83	1.95		1.54	1.60
		0.05		1.72	1.83		1.47	1.54
		0.10		1.64	1.74		1.42	1.48

Table 8. Least detectable true ratios (LDTR) in geometric mean abundance of the five most abundant fish species caught in standard series trawls and station R trawls at Cook Plant study areas, southeastern Lake Michigan, during 1975-1979. Values are given as functions of type I error (alpha = a) and power. Comparisons are of 1-yr preoperational sampling to 1-yr operational sampling and 2-yr preoperational sampling to 2-yr operational sampling at one area. Each LDTR is expressed as the ratio of the operational value to the preoperational value of the quantity "mean number per trawl tow plus one." n = sample size; MSE = mean square error of ANOVA; df = degrees of freedom of MSE.

			2-yr sampling			4-yr sampling		
				Power			Power	
MSE	df	a	n	0.90	0.95	n	0.90	0.95
			Alewife					
0.1551	350	0.01	28	2.55	2.78	56	1.94	2.06
		0.02		2.40	2.62		1.86	1.97
		0.05		2.19	2.40		1.74	1.85
		0.10		2.03	2.22		1.65	1.76
			Rainbow smelt					
0.0676	350	0.01	28	1.85	1.96	56	1.55	1.61
		0.02		1.78	1.89		1.50	1.57
		0.05		1.68	1.78		1.44	1.50
		0.10		1.60	1.69		1.39	1.45
			Spottail shiner					
0.0644	350	0.01	28	1.83	1.93	56	1.53	1.59
		0.02		1.76	1.86		1.49	1.55
		0.05		1.66	1.76		1.43	1.49
		0.10		1.58	1.67		1.38	1.44
			Trout-perch					
0.0544	250	0.01	20	1.93	2.05	40	1.59	1.66
		0.02		1.85	1.96		1.54	1.61
		0.05		1.73	1.84		1.48	1.54
		0.10		1.64	1.75		1.42	1.48
			Yellow perch					
0.0995	250	0.01	20	2.43	2.64	40	1.87	1.98
		0.02		2.29	2.49		1.80	1.91
		0.05		2.11	2.29		1.69	1.80
		0.10		1.96	2.13		1.61	1.71

Table 9. Least detectable true ratios (LDTR) in geometric mean abundance of the five most abundant fish species caught in standard series gill nets at Cook Plant study areas, southeastern Lake Michigan, during 1973-1979. Values are given as functions of type I error (alpha = a) and power. Comparisons are of 1-yr preoperational sampling to 1-yr operational sampling and 2-yr preoperational sampling to 2-yr operational sampling at one area. Each LDTR is expressed as the ratio of the operational value to the preoperational value of the quantity "mean number per gill net set plus one." n = sample size; MSE = mean square error of ANOVA; df = degrees of freedom of MSE.

			2-yr sampling			4-yr sampling		
				Power			Power	
MSE	df	a	n	0.90	0.95	n	0.09	0.95
			Alewife					
0.1177	30	0.01	24	2.52	2.76	48	1.92	2.05
		0.02		2.36	2.58		1.84	1.95
		0.05		2.15	2.35		1.72	1.83
		0.10		1.99	2.17		1.62	1.73
			Spottail shiner					
0.0957	30	0.01	24	2.30	2.50	48	1.80	1.91
		0.02		2.17	2.35		1.73	1.83
		0.05		1.99	2.16		1.63	1.72
		0.10		1.86	2.01		1.55	1.64
			Trout-perch					
0.0547	24	0.01	10	2.69	2.96	20	2.02	2.15
		0.02		2.50	2.75		1.01	2.05
		0.05		2.26	2.48		1.78	1.90
		0.10		2.07	2.28		1.68	1.79
			Yellow perch					
0.0707	18	0.01	16	2.49	2.71	32	1.90	2.03
		0.02		2.32	2.53		1.81	1.93
		0.05		2.10	2.29		1.69	1.80
		0.10		1.94	2.12		1.60	1.70

Table 10. Least detectable true ratios (LDTR) in geometric mean abundance of the five most abundant fish species caught in standard series gill nets and stations R and Q gill nets at Cook Plant study areas, southeastern Lake Michigan, during 1975-1979. Values are given as functions of type I error (alpha = a) and power. Comparisons are of 1-yr preoperational sampling to 1-yr operational sampling and 2-yr preoperational sampling to 2-yr operational sampling at one area. Each LDTR is expressed as the ratio of the operational value to the preoperational value of the quantity "mean number per gill net set plus one." n = sample size; MSE = mean square error of ANOVA; df = degrees of freedom of MSE.

			2-yr sampling			4-yr sampling		
				Power			Power	
MSE	df	a	n	0.90	0.95	n	0.90	0.95
				Alewife				
0.1217	40	0.01	24	2.53	2.77	48	1.93	2.05
		0.02		2.37	2.59		1.84	1.96
		0.05		2.16	2.36		1.72	1.84
		0.10		2.00	2.18		1.63	1.74
				Spottail shiner				
0.1108	40	0.01	24	2.43	2.64	48	1.87	1.99
		0.02		2.28	2.48		1.79	1.90
		0.05		2.09	2.27		1.68	1.79
		0.10		1.94	2.11		1.60	1.69
				Trout-perch				
0.0531	32	0.01	10	2.61	2.86	20	1.97	2.10
		0.02		2.44	2.67		1.88	2.00
		0.05		2.21	2.42		1.75	1.87
		0.10		2.04	2.23		1.66	1.77
				Yellow perch				
0.0811	24	0.01	16	2.60	2.84	32	1.96	2.09
		0.02		2.42	2.65		1.87	1.99
		0.05		2.19	2.40		1.74	1.86
		0.10		2.02	2.21		1.64	1.75

Table 11. Least detectable true ratios (LDTR) in geometric mean abundance of the five most abundant fish species caught in standard series seines at Cook Plant study areas, southeastern Lake Michigan, during 1973-1979. Values are given as functions of type I error (alpha = a) and power. Comparisons are of 1-yr preoperational sampling to 1-yr operational sampling and 2-yr preoperational sampling to 2-yr operational sampling at one area. Each LDTR is expressed as the ratio of the operational value to the preoperational value of the quantity "mean number per seine haul plus one." n = sample size; MSE = mean square error of ANOVA; df = degrees of freedom of MSE.

			2-yr sampling			4-yr sampling		
				Power			Power	
MSE	df	a	n	0.90	0.95	n	0.90	0.95
				Alewife				
0.1474	293	0.01	28	2.49	2.71	56	1.90	2.02
		0.02		2.35	2.56		1.83	1.94
		0.05		2.15	2.34		1.72	1.83
		0.10		2.00	2.18		1.63	1.73
				Rainbow smelt				
0.0821	84	0.01	8	3.65	4.13	16	2.50	2.73
		0.02		3.35	3.79		2.35	2.56
		0.05		2.95	3.34		2.15	2.34
		0.10		2.65	3.00		1.99	2.17
				Spottail shiner				
0.2199	293	0.01	28	3.04	3.38	56	2.20	2.37
		0.02		2.83	3.15		2.09	2.25
		0.05		2.55	2.83		1.94	2.09
		0.10		2.33	2.58		1.82	1.96
				Trout-perch				
0.0340	147	0.01	14	1.87	1.98	28	1.56	1.62
		0.02		1.79	1.90		1.51	1.58
		0.05		1.69	1.79		1.45	1.51
		0.10		1.60	1.70		1.40	1.46
				Yellow perch				
0.1045	125	0.01	12	3.28	3.66	24	2.31	2.50
		0.02		3.03	3.39		2.19	2.37
		0.05		2.70	3.02		2.02	2.18
		0.10		2.45	2.74		1.88	2.04

estimate of power, because other contrasts between years will involve a larger sample size, resulting in smaller values of LDTR (greater power). Comparison of 2-yr preoperational data to 2-yr operational data at a given area or station represents a more typical comparison, using all available preoperational data to detect changes in operational abundance. Restriction of comparisons to one area or station conforms the power analysis to the Year x Area interaction term, the one term in ANOVA of most value in detecting potential plant effects on fish abundance. Note that MSE and degrees of freedom refer to the full ANOVA using data from all 7 years, thus comprising the best estimate of true population variance of sampling. Values presented in earlier reports (Jude et al. 1975, 1979) used MSE from preoperational data alone, assuming it would be appropriate for operational data as well. In all cases, MSE values have not changed markedly from preoperational to operational years, and power results indicate that power of ANOVA for all 7 years is close to that previously estimated using preoperational data alone. Values of LDTR ranged from 1.34 for spottail shiner in trawls (1973-1979 data) to 2.73 for rainbow smelt in seines for comparisons of 2-yr preoperational data with 2-yr operational data at alpha = 0.01 and power = 0.95.

Scheffe's s-method (alpha = 0.01) was used to make complex comparisons of levels of factors detected as significant by ANOVA ($P<0.01$). This procedure is less sensitive than Tukey's T-method for pairwise comparisons, but is more sensitive for complex comparisons (Scheffe 1959). Tukey's T-method was used for trout-perch catches in gill nets where Area was significant and only pairwise tests were performed.

Several complex comparisons were performed. When the main factor Year was significant, data from preoperational years (1973, 1974) were compared with data from the Unit 1 operating period (1975-1977 or 1975-1978), all

operational years (1975-1979), and the period of years when both units were operational (1978 or 1979). Unit 2 became operational in August 1978. Finally, for each year, data were compared with data from all other years combined. These comparisons were conducted to evaluate plant effects. If the Year x Area interaction was significant, years within each area were compared in the same manner as described above. Consequently, changes in abundance during operational years at the plant could be compared to changes in abundance at the reference stations.

When assumptions of ANOVA were seriously violated or when species catches contained sufficient non-zero data, the Kruskal-Wallis test was employed. This nonparametric test assumes that data are at least ordinally scaled, that variables are independent, and that random samples are drawn from a continuous distribution. Because catch data are ratio-scaled measurements, the assumption is only approximately satisfied due to many tied observations, particulary zero catches. A moderate number of ties should not seriously affect test results (Conover 1971). In all cases analyzed, raw data were examined to verify whether trends indicated by the test appeared to be biologically significant.

Kruskal-Wallis computations were completed with the Michigan Interactive Data Analysis System (Fox and Guire 1973) using a procedure that corrects for tied observations. Years, Areas, and Stations were tested for differences. Years pooled over each station were also scrutinized using Kruskal-Wallis to ascertain Year x Station interactions. Significance level was set at alpha = 0.10 to increase the power of the test to compensate for tied values. Nemenyi's pairwise comparison test (Kirk 1968) was employed to discern differences among levels of factors (alpha = 0.10). In a few cases, the Kruskal-Wallis test revealed significant differences, but Nemenyi's test showed no differences. In these cases, Nemenyi's test was performed at increased levels of alpha to detect which levels were significantly different.

RESULTS AND DISCUSSION

ABUNDANT SPECIES

Alewife

Introduction--

The alewife is an anadromous species native to the Atlantic coastal drainage. It entered Lake Michigan in 1952 and reached peak abundance in the mid 1960s (Brown 1972, Colby 1973). A massive die-off occurred in 1967 (Brown 1968). Today alewife is the most abundant species in Lake Michigan.

Alewives had a considerable impact on native fish populations in Lake Michigan. Decline of lake herring, lake whitefish, and emerald shiner was related to the increasing abundance of alewives (Smith 1970). Alewives are zooplankton feeders and serve as a main food source for salmonid and other predatory fishes in Lake Michigan. They have been caught commercially for fish meal and pet food.

Alewives live in deep water during winter. They migrate to shallow areas to spawn during spring and early summer and return to deep water during summer. Young-of-the-year (YOY) inhabit shallow water during summer and migrate offshore in the fall. Alewife was the most abundant species in the study area, accounting for 42 to 87% of total annual catches (Appendix 4). Alewives were caught in large numbers by all three fishing gear (Appendices 5-7).

Trawl Data--

Trawling accounted for 2.5 to 24.5% of all alewives collected annually during 1973-1979. YOY made up the major portion of trawl catches in 1978 while

older fish predominated in 1974. Approximately the same number of YOY and older fish were trawled during other years of the 7-year period. Trawling data from April to October were analyzed by ANOVA. Catches during November were excluded because of low numbers of alewives collected.

Years--The main effect Year was highly significant for 1973-1979 and 1975-1979 data (Tables 12 and 13). Trawl catches varied considerably during the 7-year period. Large catches during 1973, 1976, and 1979 were the source of significance for the Year effect. Scheffe's test revealed that catches during the preoperational period (1973-1974) were significantly larger than those during operational years (1975-1979). Besides large fluctuations, geometric mean catches showed a generally declining trend in the number of alewives in the study area during 1973-1979. The significant difference between preoperational and operational period catches (Table 12) may be due to a lakewide decline in alewife abundance during the 1970s, also observed in other areas of Lake Michigan (Jude et al. 1980). The effect of plant operation is, therefore, confounded with lakewide alewife abundance changes and cannot be determined by analysis of the year factor alone.

The month effect was also significant. The significant Year x Month interaction (Table 12) showed that monthly catches of alewives varied among years. Large monthly catch fluctuations from year to year were observed during spring (Fig. 2) due to variations in numbers of adult during inshore migrations. Large catches in April 1973 and 1974 and during May 1974 and 1976 may be due to strong year classes of mature alewives. Relatively warm water during spring 1973, 1974, and 1976 may in part attract large numbers of adults to inshore areas during April and May. Catch variabilities were also observed during August-October (Fig. 2), probably due to fluctuating year-class strength of YOY.

Table 12. Analysis of variance summary for log(catch + 1) of alewives. Fish were trawled from April to October, 1973-1979 in Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df#	Adjusted mean square##	F-statistic	Attained significance
Year	6	11.5851	77.1353	0.0000**
Month	6	5.5757	37.1238	0.0000**
Area	1	0.4581	3.0506	0.0815
Depth	1	5.4129	36.0396	0.0000**
Time	1	5.7613	38.3594	0.0000**
Y x M	36	4.6699	31.0929	0.0000**
Y x A	6	1.2370	8.2361	0.0000**
M x A	6	0.4190	2.7895	0.0114
Y x D	6	0.4119	2.7425	0.0127
M x D	6	0.5905	3.9314	0.0008**
A x D	1	0.4085	2.7201	0.0999
Y x T	6	0.6606	4.3980	0.0003**
M x T	6	7.3088	48.6627	0.0000**
A x T	1	0.1051	0.6995	0.4035
D x T	1	0.7573	5.0420	0.0253
Y x M x A	36	0.5093	3.3907	0.0000**
Y x M x D	36	0.2657	1.7689	0.0051*
Y x A x D	6	0.1071	0.7131	0.6392
M x A x D	6	0.8071	5.3736	0.0000**
Y x M x T	36	2.6275	17.4944	0.0000**
Y x A x T	6	1.1779	7.8423	0.0000**
M x A x T	6	0.8517	5.6707	0.0000**
Y x D x T	6	0.2223	1.4799	0.1837
M x D x T	6	0.2080	1.3846	0.2195
A x D x T	1	0.4478	2.9814	0.0850
Y x M x A x D	36	0.3385	2.2540	0.0001**
Y x M x A x T	36	0.3996	2.6608	0.0000**
Y x M x D x T	36	0.3938	2.6220	0.0000**
Y x A x D x T	6	0.1084	0.7216	0.6325
M x A x D x T	6	0.3726	2.4808	0.0229
Y x M x A x D x T	36	0.2134	1.4205	0.0592
Within cell error	390	0.1502		

\# Two degrees of freedom were subtracted from the error term to correct for two missing observations where cell means were substituted.

\## Mean squares were multiplied by harmonic mean cell size/maximum cell size (nh/n = 0.9949) to correct for two missing observations where cell means were substituted.

** Highly significant (P <0.01).

* Significant (P <0.01).

Table 13. Analysis of variance summary for log(catch + 1) of alewives. Fish were trawled from April to October, 1975-1979 in Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df	Mean square	F-statistic	Attained significance
Year	4	9.6048	61.9246	0.0000**
Month	6	10.3319	66.6124	0.0000**
Station	4	1.4325	9.2354	0.0000**
Time	1	0.9219	5.9438	0.0153
Y x M	24	5.2558	33.8853	0.0000**
Y x S	16	0.4352	2.8058	0.0003**
M x S	24	0.4886	3.1499	0.0000**
Y x T	4	0.8774	5.6569	0.0002**
M x T	6	7.1485	46.0883	0.0000**
S x T	4	1.2744	8.2166	0.0000**
Y x M x S	96	0.2866	1.8478	0.0000**
Y x M x T	24	2.8575	18.4233	0.0000**
Y x S x T	16	0.1585	1.0217	0.4327
M x S x T	24	0.1760	1.1344	0.3029
Y x M x S x T	96	0.2762	1.7808	0.0001**
Within cell error	350	0.1551		

** Highly significant (P <0.001).

Water temperatures and weather conditions during trawling may also affect monthly catches of YOY alewives.

Areas--Area effect (Cook and Warren Dunes) was not significant, indicating that plant operation had no effect on alewife abundance. In general annual catches of alewives at Cook and Warren Dunes were similar during the 7-year period, except for 1973 and 1974. In 1973 catches were larger at Warren Dunes than at Cook while in 1974 larger catches were observed at Cook. Geometric mean catches ranged from 2.9 to 27.2 at Cook and 3.7 to 36.8 at Warren Dunes during 1973-1979.

The significant Month x Area interaction demonstrated that monthly catches varied between Cook and Warren Dunes. Larger catches of YOY were observed at

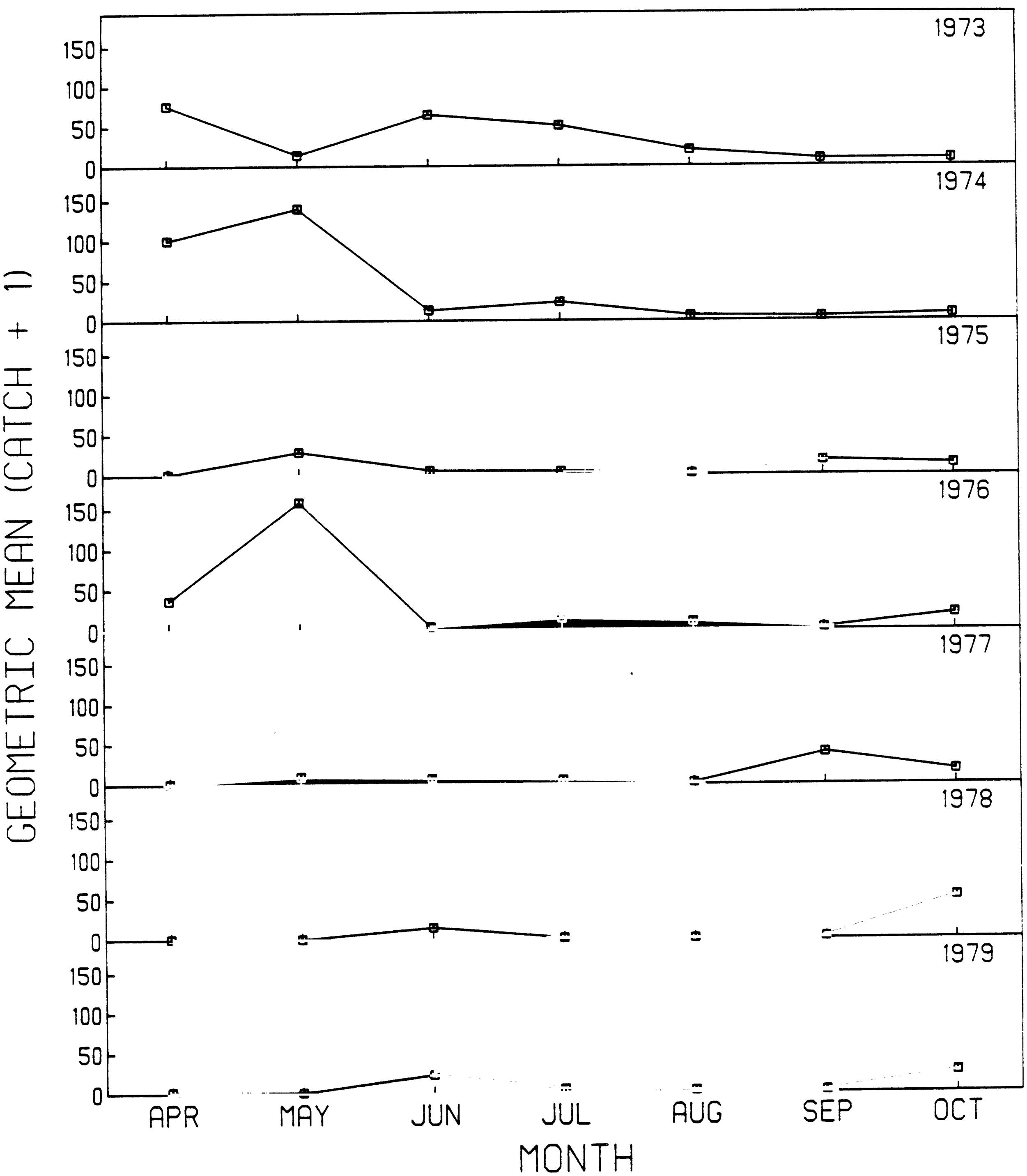


Fig. 2. Monthly geometric mean number of alewives caught by standard series trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

Warren Dunes than Cook during August 1973 (Fig. 3). YOY were abundant in the shallow area during late summer. They avoided Cook Plant areas in August 1973 probably because of an upwelling of cold water (8.5 to 12.2°C). Water temperatures at the Warren Dunes trawl stations were 12.4 to 15.8°C during the August 1973 sampling period. Larger catches of YOY at Warren Dunes than at Cook were also found during October 1978. During May 1976 and June 1973, adult alewife catches were larger at Warren Dunes than at Cook, while during May 1974 larger catches of adults occurred at Cook (Fig. 3). These data indicated that plant operation was not the source of significance of the Month x Area interaction.

The significant Year x Area interaction indicates differential changes in yearly abundance of alewives between Cook and Warren Dunes. This significance resulted primarily from differences in catches between the two areas during 1973 and 1974 (Fig. 4). Large catches at Warren Dunes in 1973 were due to unusually large numbers of YOY in August. Large catches at Cook in 1974 resulted from great abundance of adults during May to July 1974. During 1975-1979 catches at Cook and Warren Dunes were similar. As previously mentioned, variations of catches between the two areas in August 1973 and May-July 1974 were caused by factors other than plant operation.

Trawling at station R (6 m, north Cook) was added to the study in 1975 to assess more fully the effects of plant operation on fish populations. Main effect Year, Station, and Month and several interactions were significant for 1975-1979 trawl data that included catches at station R (Table 13). Scheffe's test showed that catches during one-unit operation (1975-1977) were larger than those during two-unit operation (1978-1979) for all stations combined and for each station tested separately, except station G (6 m, Warren Dunes). There was, however, no significant difference between the two levels of operation when

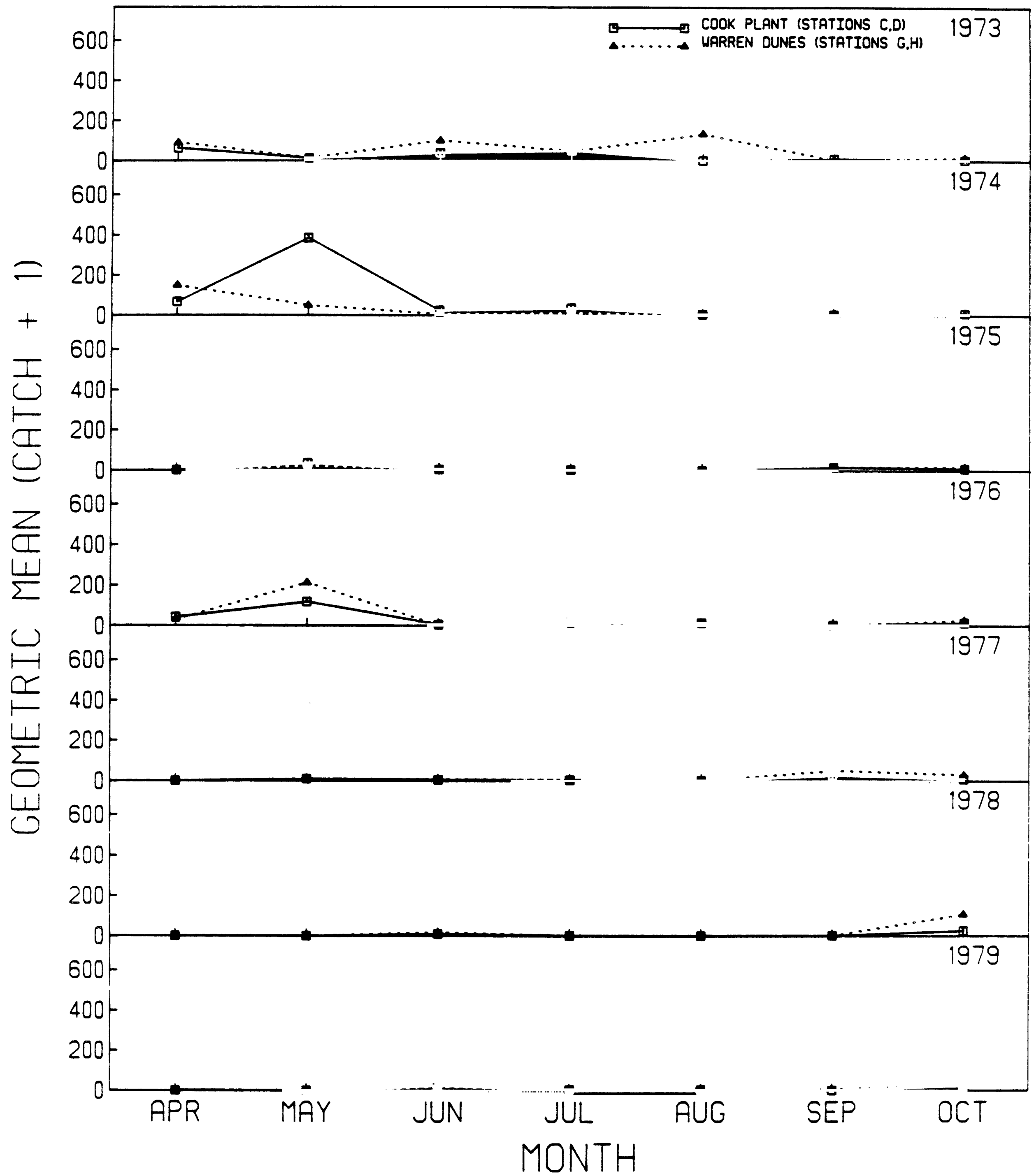


Fig. 3. Monthly geometric mean number of alewives caught by standard series trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

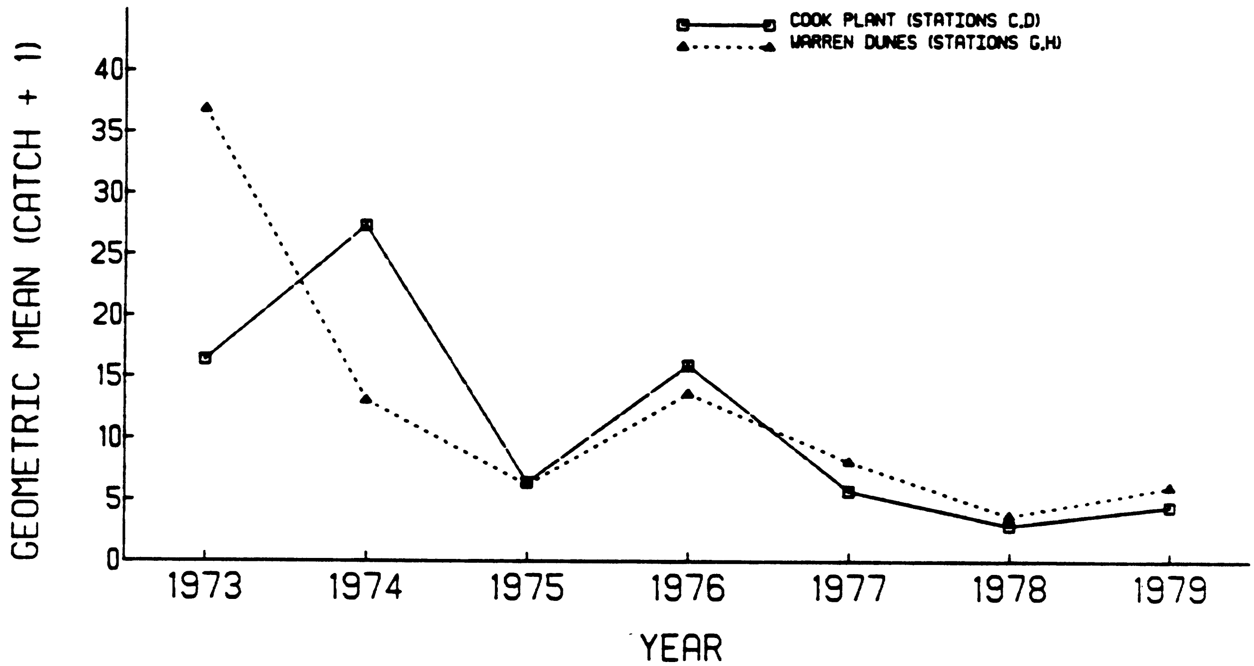


Fig. 4. Yearly geometric mean number of alewives caught by standard series trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

1978 was included in one-unit operation (1975-1978 vs. 1979). These conflicting results when one and two units were compared were due to unusually low catches in 1978 and exceptionally high catches in 1976.

The significant station effect (R, C, D, G, and H) indicated possible plant effects. Scheffe's test, however, revealed that catches at the 6-m stations C and R at Cook were not significantly different from catches at Warren Dunes 6-m station G. Geometric mean catches at 6-m stations R, C, and G were 7.3, 9.0, and 7.7, respectively. Catches at station D (9 m, Cook) and station H (9 m, Warren Dunes) were similar. The significance of Station effect was due mainly to the catch difference between stations R and D, with respective geometric mean catches of 9.0 and 4.9.

The significant Station x Month interaction showed that monthly catches varied among stations. Variations of monthly catches were due mostly to fluctuations of adult catches during spring and YOY catches in the fall (Fig. 5). Catches of adults at one station may exceed catches at another station for a particular month, but there was no long-term trend of increased catches at any station during the operational period (Fig. 5). These data suggested the significance of the Station x Month interaction was not related to plant operation. The general decline of alewife populations during 1973-1979, the conflicting results of one-unit and two-units comparison, and the nonsignificance of catch differences at stations R, C, and G suggest the significance of Year x Station interaction was due to factors other than plant operation.

Gill Net Data--

Fewer alewives were caught in gill nets than in trawls or seines. Gill nets accounted for 2.0 to 12.5% of the annual alewife catch during 1973-1979. Gill net catches were comprised mostly of adults and represented a major portion of all adults collected. Gill net data from April to September were analyzed by ANOVA. October and November data were excluded due to low numbers of alewives collected.

Years--The ANOVA showed that the main factor Year was highly significant (Table 14). Gill net catches varied greatly during 1973-1979, ranging from 2,259 in 1978 to 11,104 in 1973. Scheffe's test showed that catches during preoperational years (1973-1974) were significantly higher than catches during operational years (1975-1979). Mean annual catches were 10,264 during the preoperational period and 2,266 during the operational period. Gill net catches generally declined during the study period. A modest catch increase was

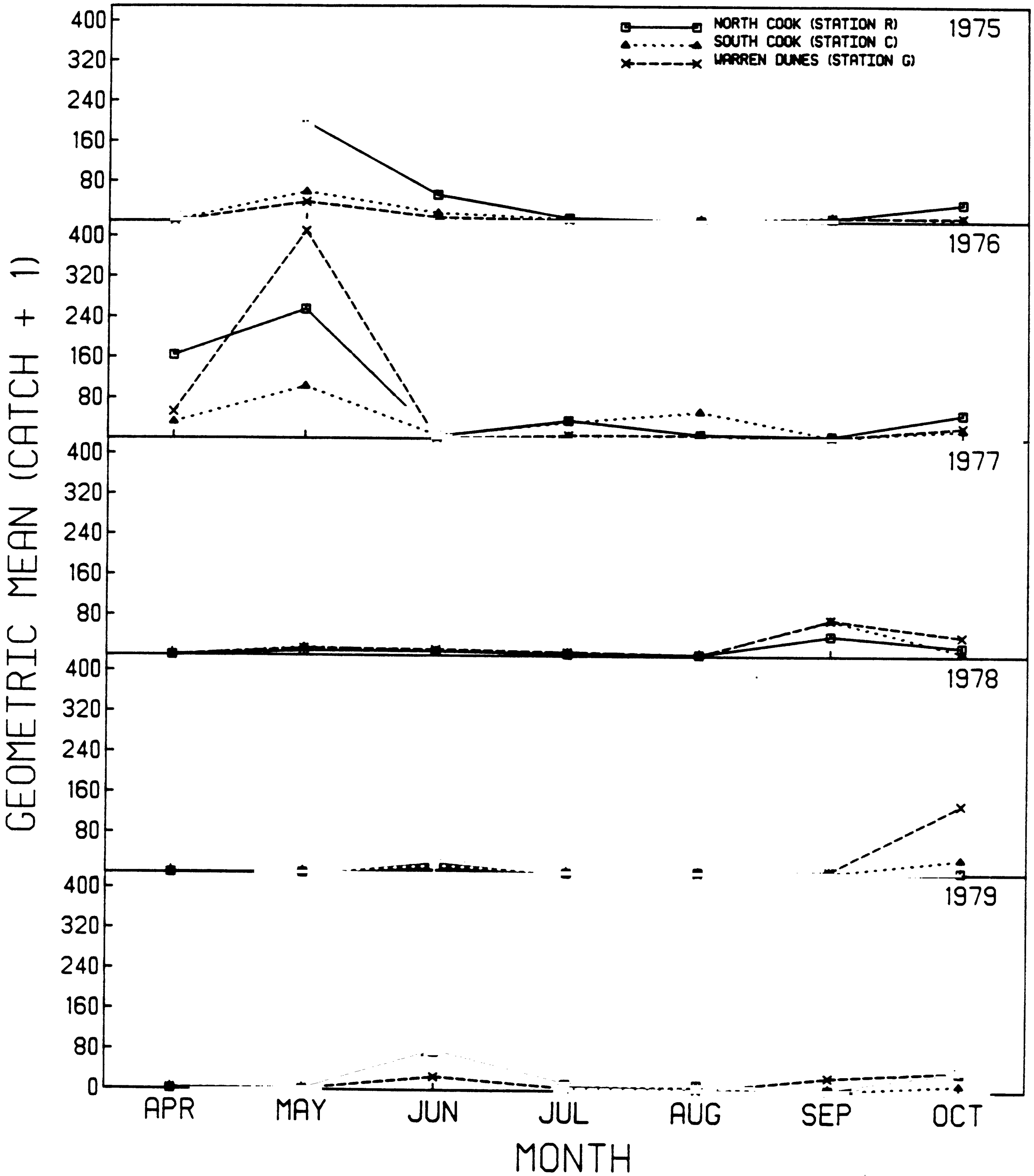


Fig. 5. Monthly geometric mean number of alewives caught during operational years 1975-1979 by standard series and station R trawling in Cook Plant study areas, southeastern Lake Michigan.

Table 14. Analysis of variance summary for log(catch + 1) of alewives. Fish were gillnetted from April to September, 1973-1979 in Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df	Mean square	F-statistic	Attained significance
Year	6	5.4694	46.4513	0.0000**
Month	5	13.8400	117.5430	0.0000**
Area	1	0.1428	1.2125	0.2796
Depth	1	0.2307	1.9592	0.1785
Time	1	12.0963	102.7339	0.0000**
Y x M	30	1.2335	10.4758	0.0000**
Y x A	6	0.2167	1.8402	0.1247
M x A	5	0.3615	3.0704	0.0235
Y x D	6	0.0841	0.7142	0.6410
M x D	5	0.8482	7.2036	0.0002**
A x D	1	0.4451	3.7799	0.0613
Y x T	6	1.5615	13.2615	0.0000**
M x T	5	0.4266	3.6230	0.0111
A x T	1	0.0653	0.5546	0.4622
D x T	1	0.7788	6.6147	0.0153
Y x M x A	30	0.3342	2.8384	0.0028*
Y x M x D	30	0.4103	3.4843	0.0005**
Y x A x D	6	0.1051	0.8924	0.5129
M x A x D	5	0.0124	0.1057	0.9902
Y x M x T	30	0.4534	3.8511	0.0002**
Y x A x T	6	0.5121	4.3496	0.0028**
M x A x T	5	0.1274	1.0824	0.3900
Y x D x T	6	0.1205	1.0237	0.4292
M x D x T	5	0.0634	0.5387	0.7453
A x D x T	1	0.1583	1.3440	0.2555
Y x M x A x D	30	0.1599	1.3588	0.2030
Y x M x A x T	30	0.1146	0.9735	0.5289
Y x M x D x T	30	0.2973	2.5251	0.0067*
Y x A x D x T	6	0.0806	0.6847	0.6633
M x A x D x T	5	0.1022	0.8682	0.5139
Y x M x A x D x T#	30	0.1177		

** Highly significant (P <0.001).
* Significant (P <0.01).
# The Y x M x A x D x T interaction is assumed to be zero and its mean square is treated as the within cell error mean square.

was observed in 1976 and again in 1979. The significance of Year effect was probably due to population fluctuations and general decline of alewife abundance in Lake Michigan.

The significant Year x Month interaction established that monthly catches differed among years. Large differences in monthly catches occurred mostly during spring and late summer (Fig. 6). Large catches of adults were observed in April 1973, May 1974, and in June during both 1973 and 1974. Appreciable numbers of adults also occurred from April to July in 1976 and during June and July in 1979. Relatively small catches were observed during May and July 1973, April 1974, and during spring and early summer in 1975, 1977, and 1978. Small and large monthly catches in gill nets occurred both during preoperational and operational years suggesting that plant operation was not the source of significance for the Year x Month interaction.

Areas--Area effect (Cook and Warren Dunes) was not significant, indicating that plant operation had no effects on alewife populations. Gill net catches at Cook and Warren Dunes were similar during the study period. Mean annual catches ranged from 128 to 2,550 at Cook and 330 to 2,993 at Warren Dunes during 1973-1979.

The Year x Area interaction was not significant, indicating that annual catches at Cook and Warren Dunes were similar. The significant Month x Area interaction established that monthly catches of alewives differed between Cook and Warren Dunes. Gill net catches may be larger at Cook than Warren Dunes or vice-versa for a particular month, but there was no long-term trend in monthly catch differences between the two areas (Fig. 7). These data suggested that significance of the Month x Area interaction was not related to plant operation.

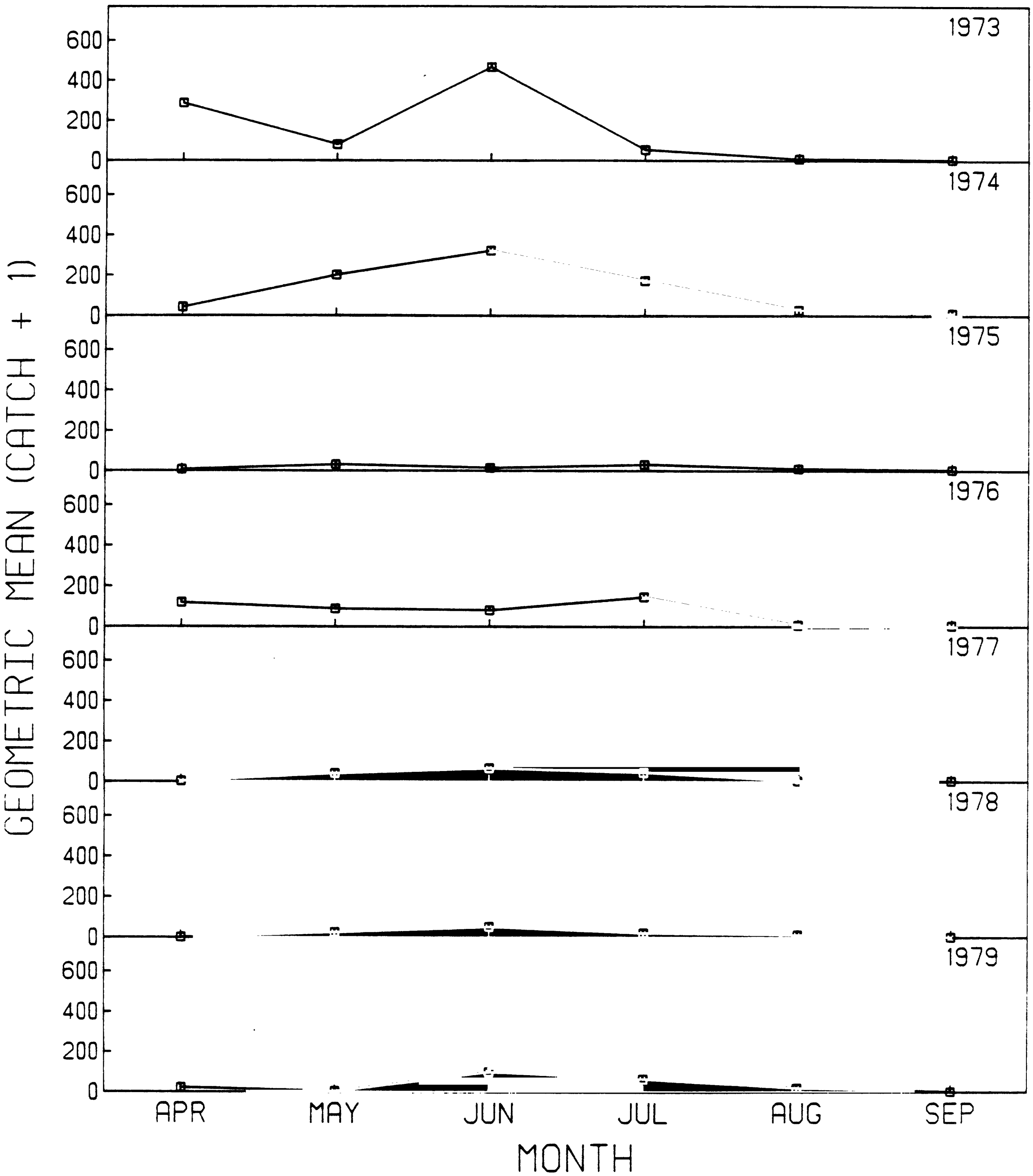


Fig. 6. Monthly geometric mean number of alewives caught by standard series gillnetting in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

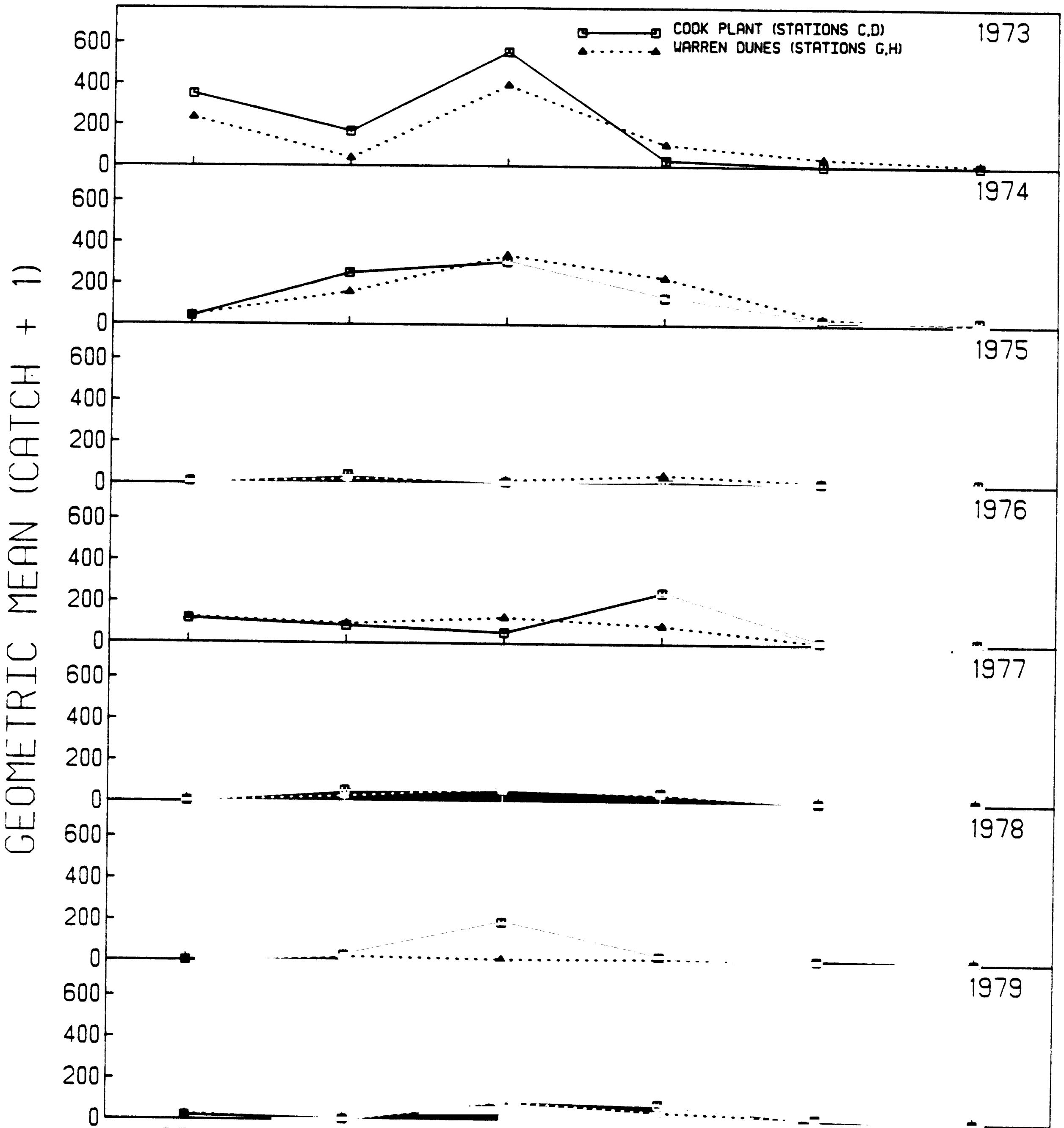


Fig. 7. Monthly geometric mean number of alewives caught by standard series gillnetting in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

Gillnetting at stations Q (9 m) and R (6 m) was added to the study in 1975 to detect more fully the changes in fish populations near the Cook Plant. The ANOVA of 1975-1979 data showed significant Year and Month effects. As was found with trawl data, comparison of gill net catches between one-unit and two-unit operation yielded inconsistent results when 1978 data were assigned to different levels (one or two unit) of operation. Catches during one-unit operation were significantly larger than those during two-unit operation when 1978 was included in two-unit operation (1975-1977 vs. 1978-1979). There was no significant difference between the two levels of operation when 1978 was included in two-unit operation (1975-1978 vs. 1979). Because Unit 2 went on line after mid-September 1978, and since gill nets captured very few alewives during September 1978, 1978 data should be included in one-unit operation.

Area main effect (north Cook, south Cook, Warren Dunes) was not significant. Alewife catches in these areas were generally similar (Fig. 8). The Year x Area and Month x Area interactions were not significant (Table 15). These ANOVA results indicate that gillnetting at stations Q and R did not show any effect of plant operation on alewife populations.

Seine Data--

Seine catches represented 66.5 to 95% of all alewives collected. The seine was the most effective gear for collecting YOY alewives. Fish in this size group accounted for 62 to 95% of the alewives collected in seines. Appreciable numbers of adults were also caught in seines, in particular during the spring inshore migration. Seine data from April to October 1973 to 1979 were analyzed by ANOVA (Table 16).

Years--Main effect Year was highly significant. Annual catches of alewives in seines fluctuated widely, ranging from 26,835 in 1978 to 135,321 in 1979.

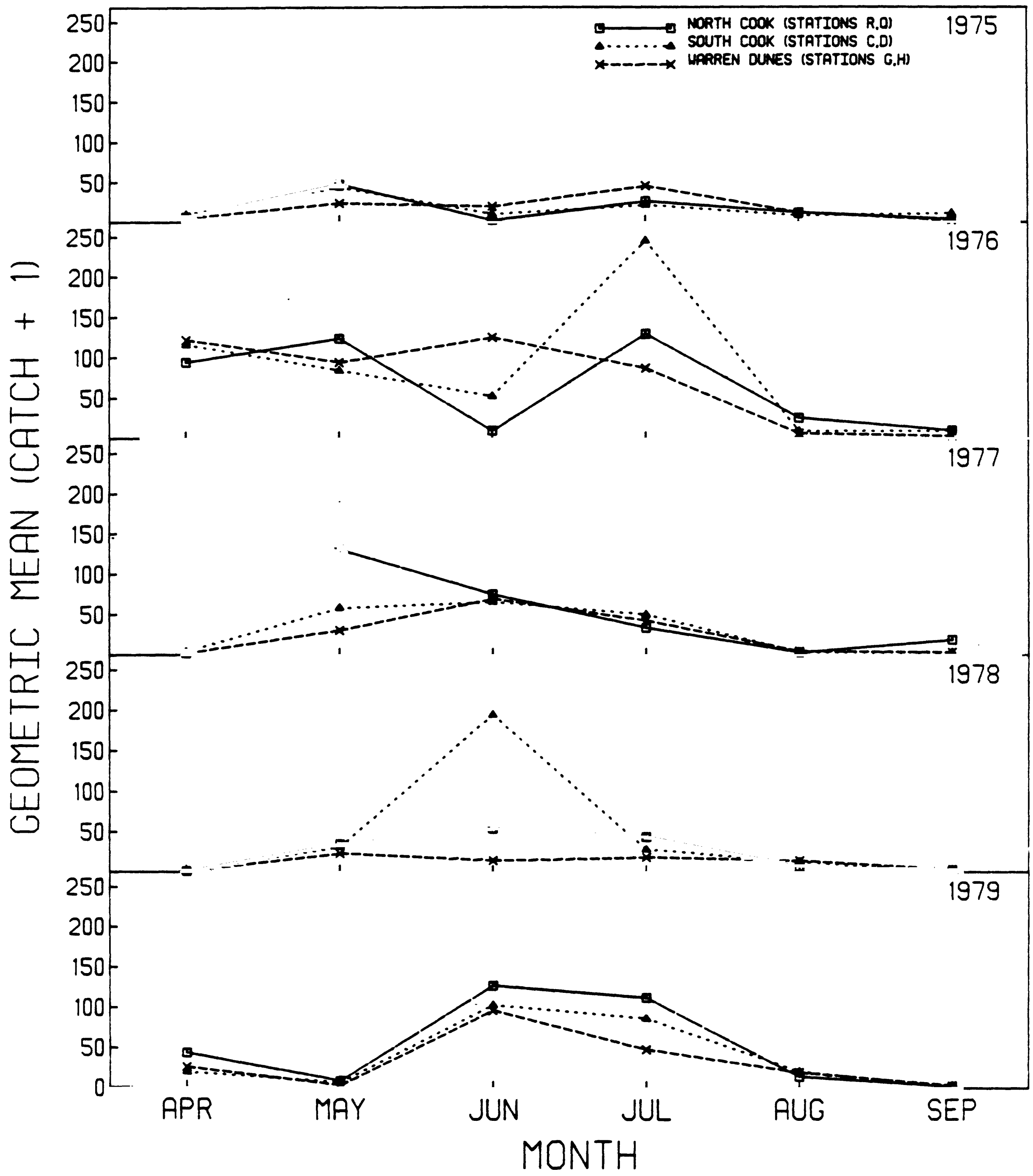


Fig. 8. Monthly geometric mean number of alewives caught during operational years 1975-1979 by standard series and stations R and Q gillnetting in Cook Plant study areas, southeastern Lake Michigan.

Table 15. Analysis of variance summary for log(catch + 1) of alewives. Fish were gillnetted from April to September, 1975-1979 in Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df	Mean square	F-statistic	Attained significance
Year	4	3.8488	31.6203	0.0000**
Month	5	11.8611	97.460	0.0000**
Area	2	0.3250	2.6697	0.0816
Depth	1	1.3978	11.4841	0.0016*
Time	1	13.6519	112.1581	0.0000**
Y x M	20	2.0747	17.0452	0.0000**
Y x A	8	0.1123	0.9227	0.5083
M x A	10	0.2586	2.1243	0.0450
Y x D	4	0.0699	0.5740	0.6830
M x D	5	1.2341	10.1388	0.0000**
A x D	2	0.1007	0.8270	0.4447
Y x T	4	1.5865	13.0344	0.0000**
M x T	5	0.3258	2.6769	0.0353
A x T	2	0.5953	4.8906	0.0126
D x T	1	0.0116	0.0957	0.7587
Y x M x A	40	0.2694	2.2130	0.0069*
Y x M x D	20	0.2580	2.1199	0.0213
Y x A x D	8	0.1273	1.0455	0.4195
M x A x D	10	0.1845	1.5156	0.1697
Y x M x T	20	0.4550	3.7380	0.0002**
Y x A x T	8	0.2475	2.0335	0.0669
M x A x T	10	0.2066	1.6972	0.1153
Y x D x T	4	0.1906	1.5663	0.2020
M x D x T	5	0.0499	0.4097	0.8392
A x D x T	2	0.2431	1.9970	0.1490
Y x M x A x D	40	0.2145	1.7620	0.0385
Y x M x A x T	40	0.2046	1.6812	0.0522
Y x M x D x T	20	0.4532	3.7231	0.0002**
Y x A x D x T	8	0.0550	0.4521	0.8818
M x A x D x T	10	0.1138	0.9352	0.5122
Y x M x A x D x T#	40	0.1217		

** Highly significant (P <0.001).

* Significant (P <0.01).

\# The Y x M x A x D x T interaction is assumed to be zero and its mean square is treated as the within cell error mean square.

Table 16. Analysis of variance summary for log(catch + 1) of alewives. Fish were seined from April to October, 1973-1979 in Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df#	Adjusted mean square##	F-statistic	Attained significance
Year	6	2.3869	16.1987	0.0000**
Month	6	32.8084	222.6500	0.0000**
Station	2	0.3897	2.6447	0.0727
Time of day	1	10.9881	74.5654	0.0000**
Y x M	36	6.4367	43.6815	0.0000**
Y x S	12	0.8334	5.6557	0.0000**
M x S	12	0.4757	3.2285	0.0002**
Y x T	6	1.8043	12.2448	0.0000**
M x T	6	22.2994	151.3321	0.0000**
S x T	2	0.1015	0.6886	0.3114
Y x M x S	72	0.8461	5.7417	0.0000**
Y x M x T	36	3.4841	23.6444	0.0000**
Y x S x T	12	0.9091	6.1697	0.0000**
M x S x T	12	0.2562	1.7386	0.0583
Y x M x S x T	72	0.5129	3.4806	0.0000**
Within cell error	293	0.1474		

One degree of freedom was subtracted from the error term to correct for a missing observation where the cell mean was substituted.

Mean squares were multiplied by harmonic cell size/maximum cell size (nh/n = 0.9966) to correct for one missing observation where the cell mean was substituted.

** Highly significant ($P < 0.001$).

Seine catches also varied considerably within operational period. Because seine catches consisted mainly of YOY, annual catch variabilities resulted primarily from year-class strength of YOY. In contrast to gill net and trawl data, geometric mean catches in seines did not show any long-term alewife population trend during 1973-1979. These data suggest that fluctuations of YOY abundance were the main source of significance of the Year effect. Scheffe's test indicated that catches during preoperational and operational years were not significantly different. Seine catches were relatively large during 1973 and

1974. During the operational period large catches occurred in 1975, 1976, and 1979 and small catches were observed in 1977 and 1978. These ANOVA results suggest YOY populations were not affected by plant operation.

As was found with analysis of trawl and gill net data, the significance of the difference in seine catches between one-unit and two-unit operation depended on how data were partitioned. Catches during 1975-1977 were significantly higher than catches during 1978-1979 for all stations combined and for station B (south Cook) and station F (Warren Dunes). At station A (north Cook), catches during 1975-1977 were not significantly different from those during 1978-1979. No significant difference was found when 1975-1978 data were compared with 1979 data for all stations combined and for each station (A, B, F). Low catches in 1978 and high catches in 1976 were the source of variabilities of the results of one- and two-unit comparisons.

The significant Year x Month interaction indicated that monthly catches varied among years. Variations in monthly catches were observed mainly during August, September, and October due to fluctuations of YOY abundance in the beach zone (Fig. 9). YOY generally remained in shallow water during late summer and migrated offshore in the fall. During the 7-year period high catches of YOY were observed in August, September, or October (Fig. 9). High catches of adults in spring and early summer occurred during any month from May to July. There was, however, no long-term trend of monthly catches of YOY or adults during 1973-1979, suggesting that the significance of the Year x Month interaction was not related to plant operation.

Areas--Main effect Station was not significant (Table 16). Catches of alewives at the three stations were similar during 1973-1979. Scheffe's test revealed no significant difference in catches between preoperational and

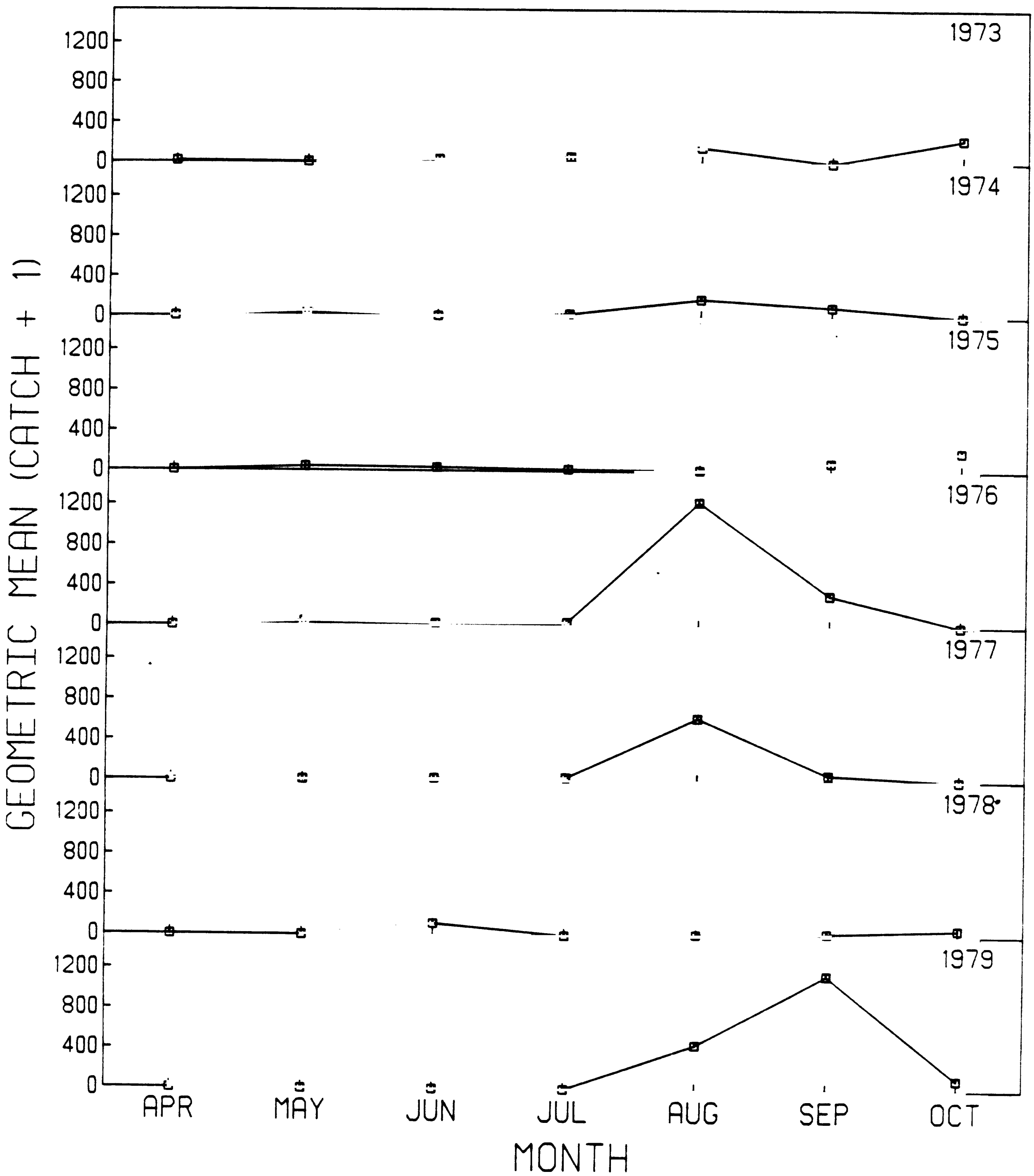


Fig. 9. Monthly geometric mean number of alewives caught by standard series seining in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

operational periods for all stations combined and for each station. These results indicated absence of plant effect on alewife populations in the beach zone. The significant Year x Station interaction showed that annual catches differed among the three seine stations. Annual catches at each station fluctuated considerably during 1973-1979 (Fig. 10). Catches at one station were usually larger or smaller than catches at other stations for any particular year during preoperational and operational periods. These data suggest that the Year x Station interaction was caused by factors other than plant operation.

The significant Month x Station interaction established that monthly catches varied among stations. Monthly catches differed mostly during August, September, and October probably due to patchiness of YOY distribution in the beach zone (Fig. 11). Seine catches at one station usually exceed those at other stations during a particular month, but there was no long-term trend of monthly catches for any station, suggesting the significance of the Month x Station interaction was not related to plant operation.

Summary of Operational Effects--

The ANOVA indicated plant operation had no significant impact on alewife populations in the study area. Several main effects and interactions were significant due to biological and environmental factors not related to plant operation. The main effect year was significant for all three types of fishing gear used, due probably to year-to-year fluctuations of alewife populations and decline of alewife abundance during 1973-1979. The significantly higher catches during preoperational than operational periods for trawls and gill nets probably resulted from the lakewide decline in alewife abundance. Catches were larger during one-unit operation than during two-unit operation when 1978 data were included in two-unit operation. This significance resulted mostly from

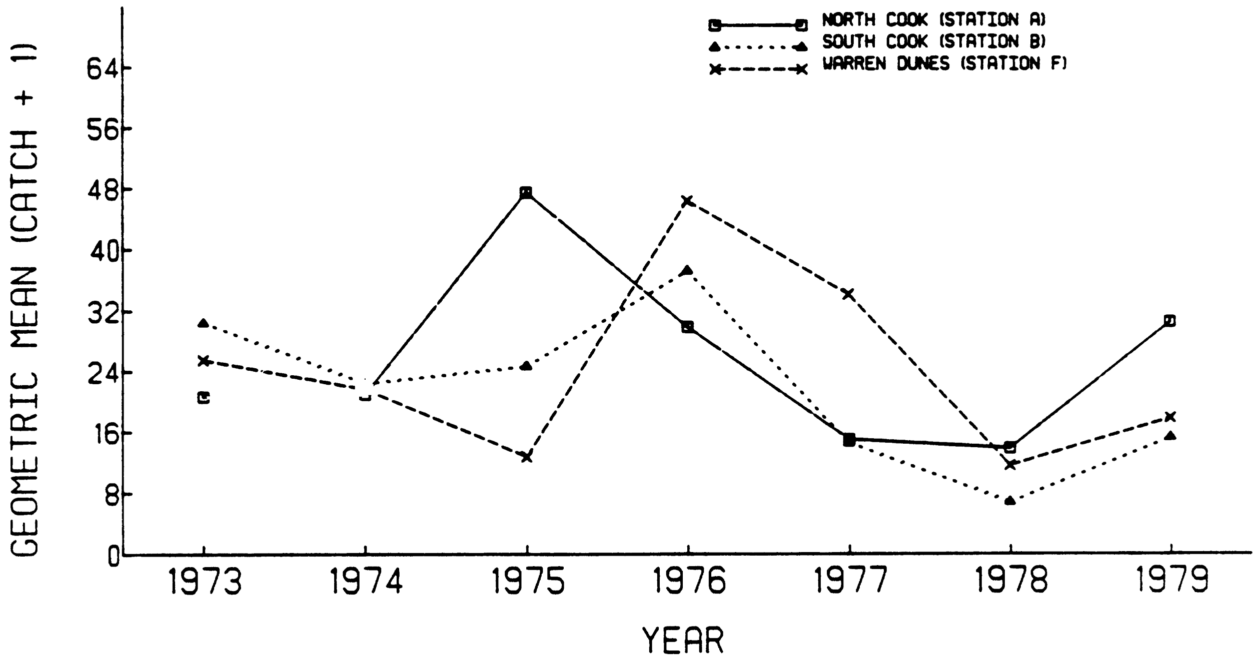


Fig. 10. Yearly geometric mean number of alewives caught by standard series seining in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

unusually small catches in 1978 and high catches in 1976. Area effect (Cook, Warren Dunes) was not significant for any type of fishing gear used. The significant main effect Station (R, C, D, G, H) for trawl data was due to a catch difference at stations R and D and was not related to plant operation. Several interactions, Year x Area, Year x Station, Year x Month, and Area x Month were significant. Biological factors (migration, schooling) and environmental factors (upwelling, weather conditions) were the main source of significance of these interactions.

Distribution and Growth by Age-group--

Three age-groups of alewives, YOY, yearlings, and adults (age 2+), were delineated from monthly length-frequency distributions of all fish caught (Fig. 12).

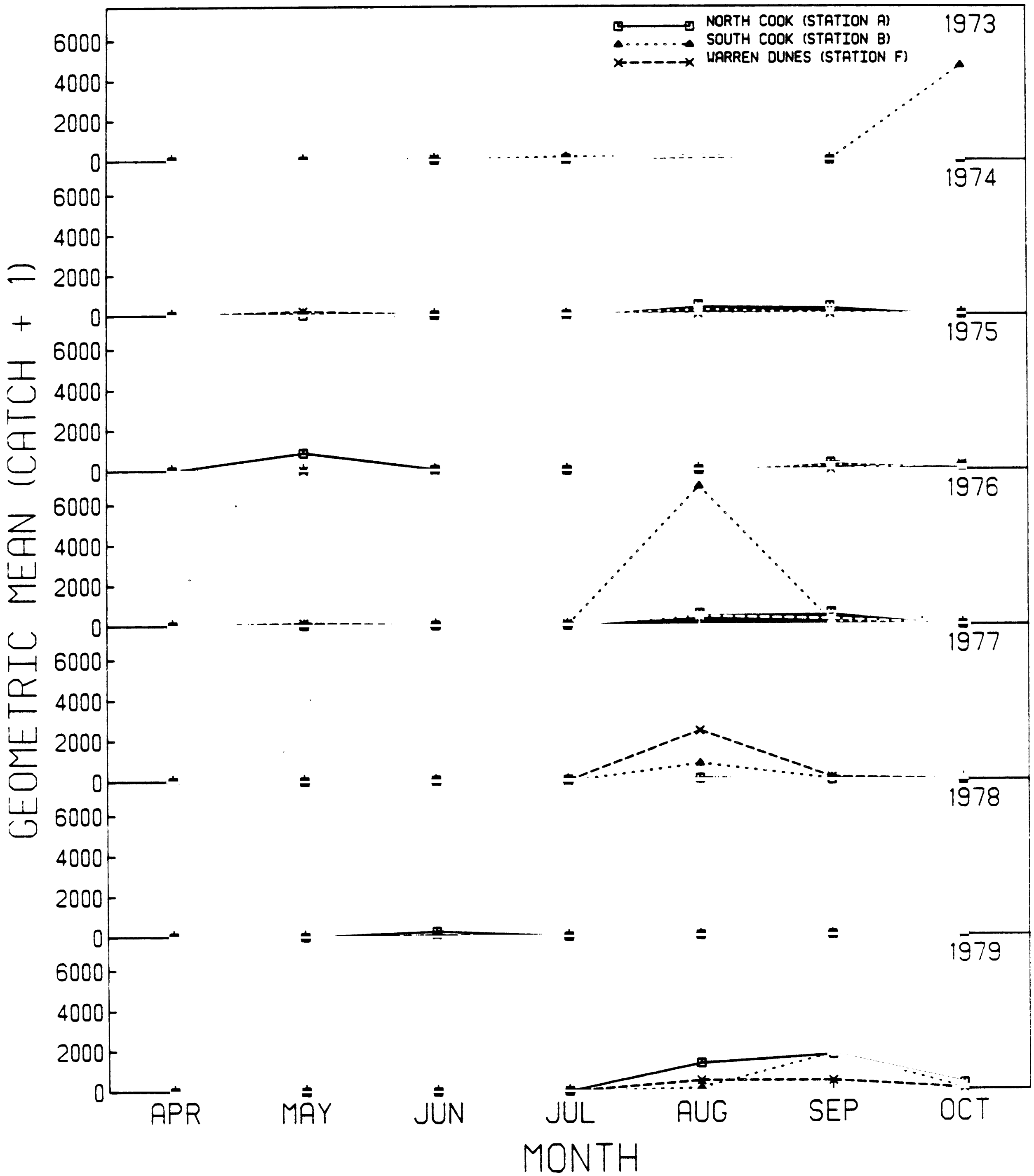


Fig. 11. Monthly geometric mean number of alewives caught by standard series seining in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

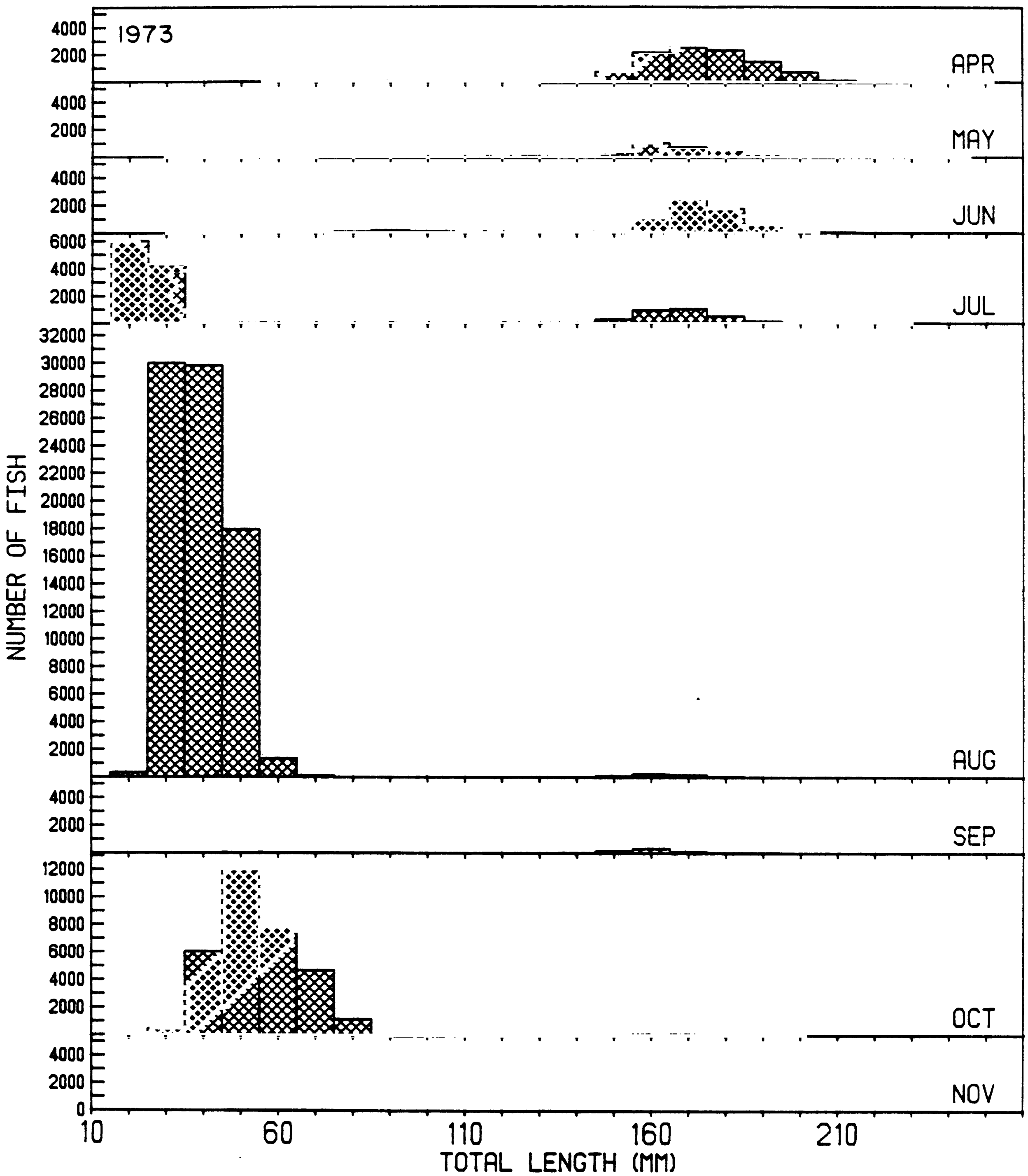


Fig. 12. Monthly length-frequency histograms of alewives caught during 1973-1979 by standard series trawling, gillnetting, and seining in Cook Plant study areas, southeastern Lake Michigan.

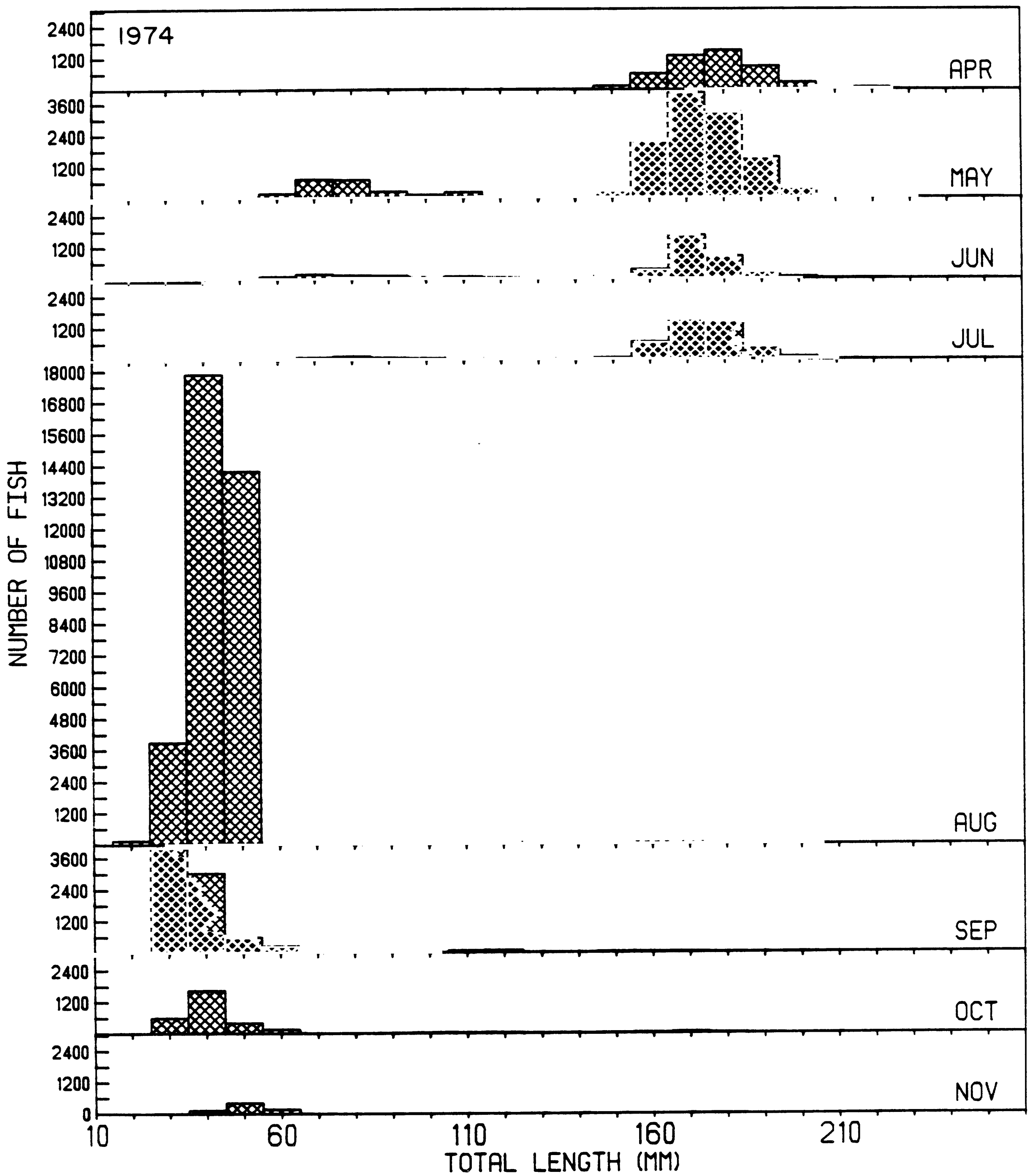
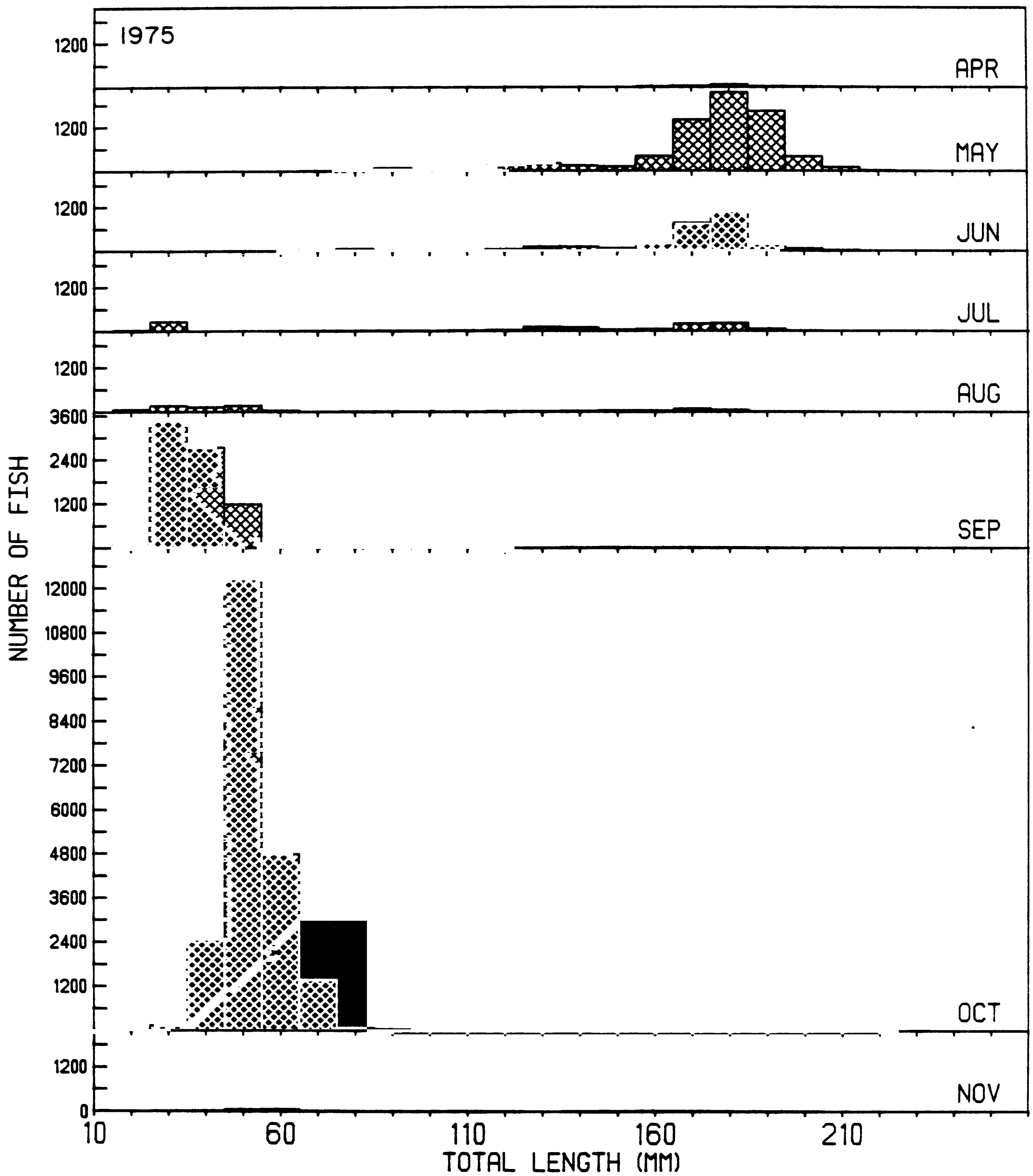


Fig. 12. Continued.



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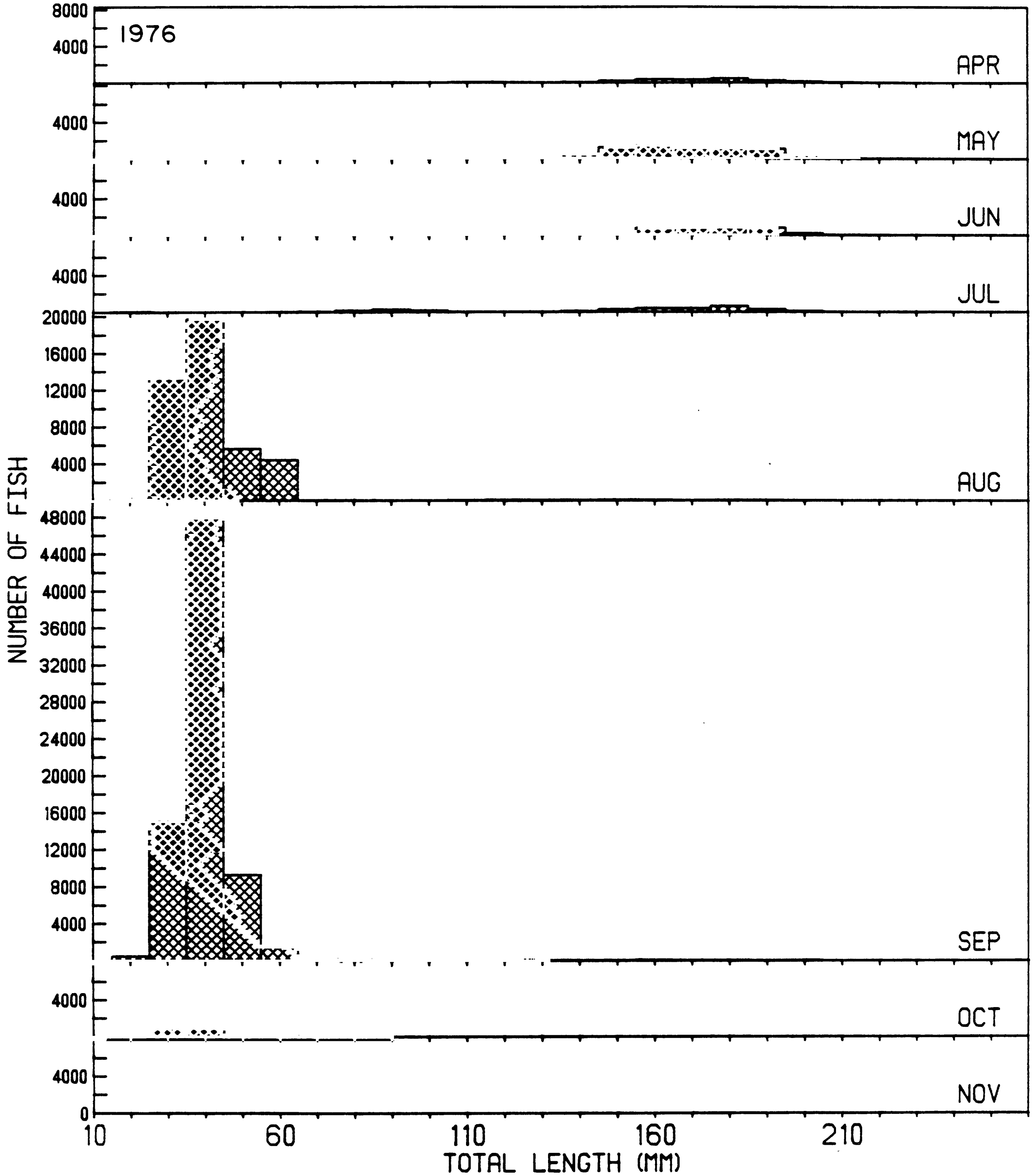

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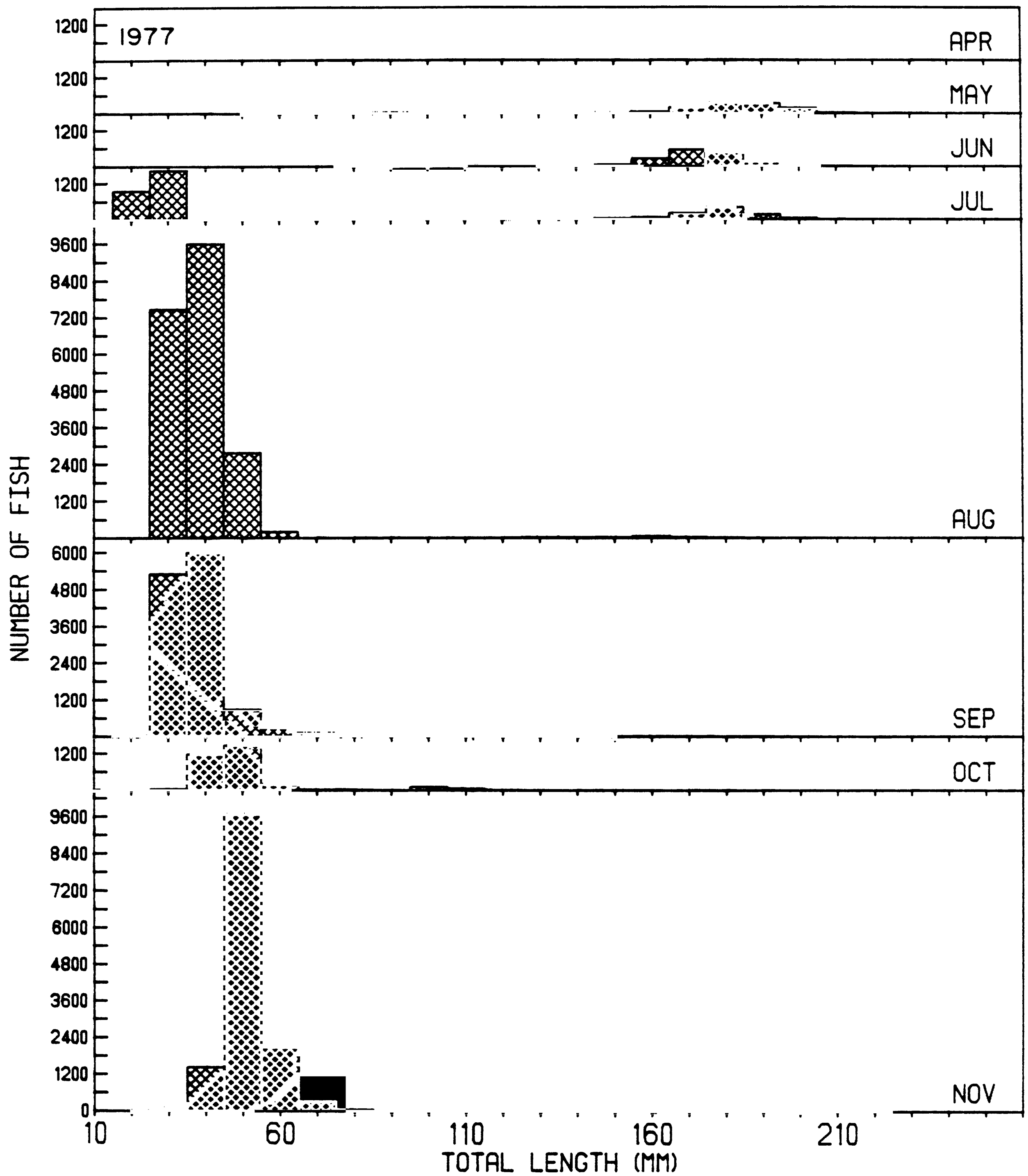

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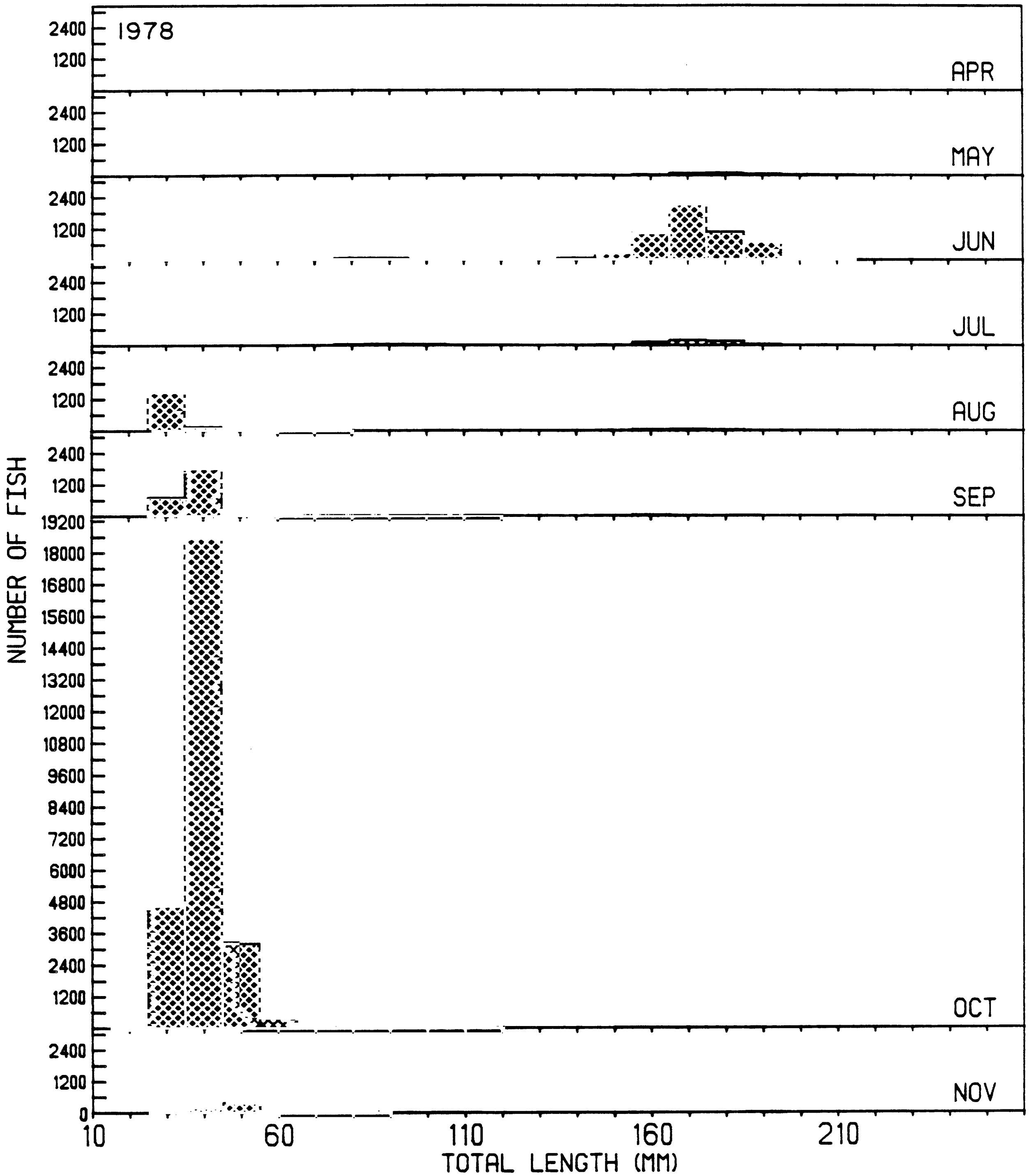

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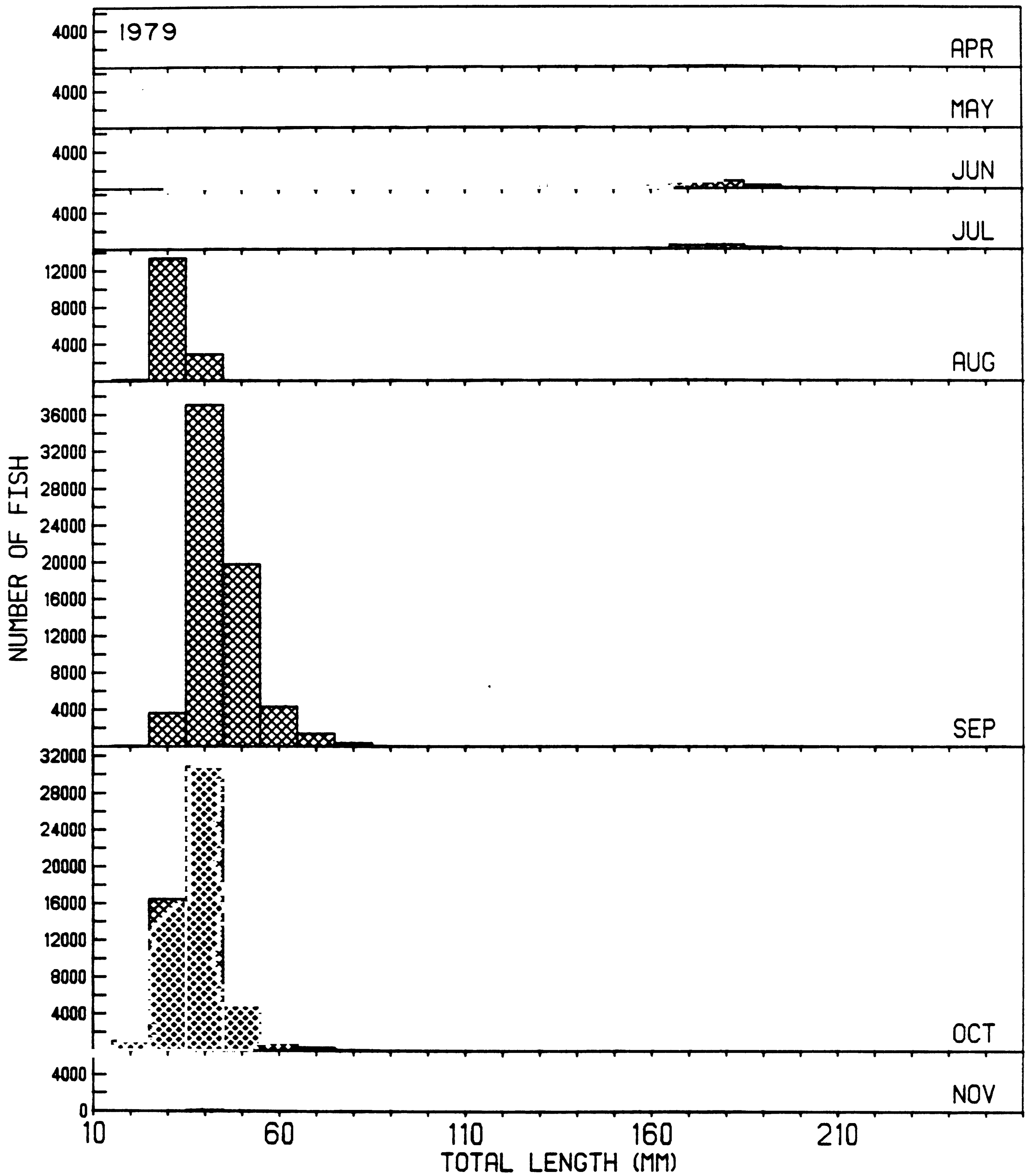


Fig. 12. Continued.

Young-of-the-Year--YOY (25-85 mm) were the most abundant age-group, accounting for 62 to 97% of the annual alewife catches. YOY were first collected in standard series sampling during July in 1973, 1975, 1977, and 1978. In 1974, 1976, and 1979, YOY first entered the catches in August. YOY migrate offshore in the fall (Graham 1956). In the study area, YOY catches in October and November were generally lower than during August or September. During 1975 and 1978, however, largest monthly catches were observed in October (Fig. 12). Annual catches of YOY varied considerably over the 7-year period, ranging from 31,721 in 1978 to 137,400 in 1979. High YOY abundance was observed in 1973, 1976, and 1979, while low abundance occurred during 1974, 1975, and 1978 (Fig. 12). Weak and strong year classes of YOY occurred during preoperational and operational years.

Alewife larvae first hatched in June at a mean length of approximately 4 mm. The average length of YOY collected yearly ranged from 23 to 28 mm in their first month of occurrence (Fig. 13). Growth rate during the first month of life (from June to July) varied from 0.64 to 0.79 mm/day over the 7-year period. Fish larvae data indicated a major hatching took place during July. During August, mean length of YOY ranged from 33 to 40 mm over 1973-1979 (Fig. 13), corresponding to a monthly growth rate of 9.0 to 13 mm or a daily growth rate of 0.30 to 0.47 mm. This slower growth from July to August than from June to July partly resulted from the recruitment into August catches of younger YOY that hatched during July. Fluctuations of calculated monthly growth rates of YOY from year to year during July-September (Fig. 13) were in part due to variation in the proportion of YOY from different cohorts in the samples. Except for 1975, YOY showed very little or negative growth from September to October during 1973-1979 (Fig. 13). This discrepancy in YOY growth rate could

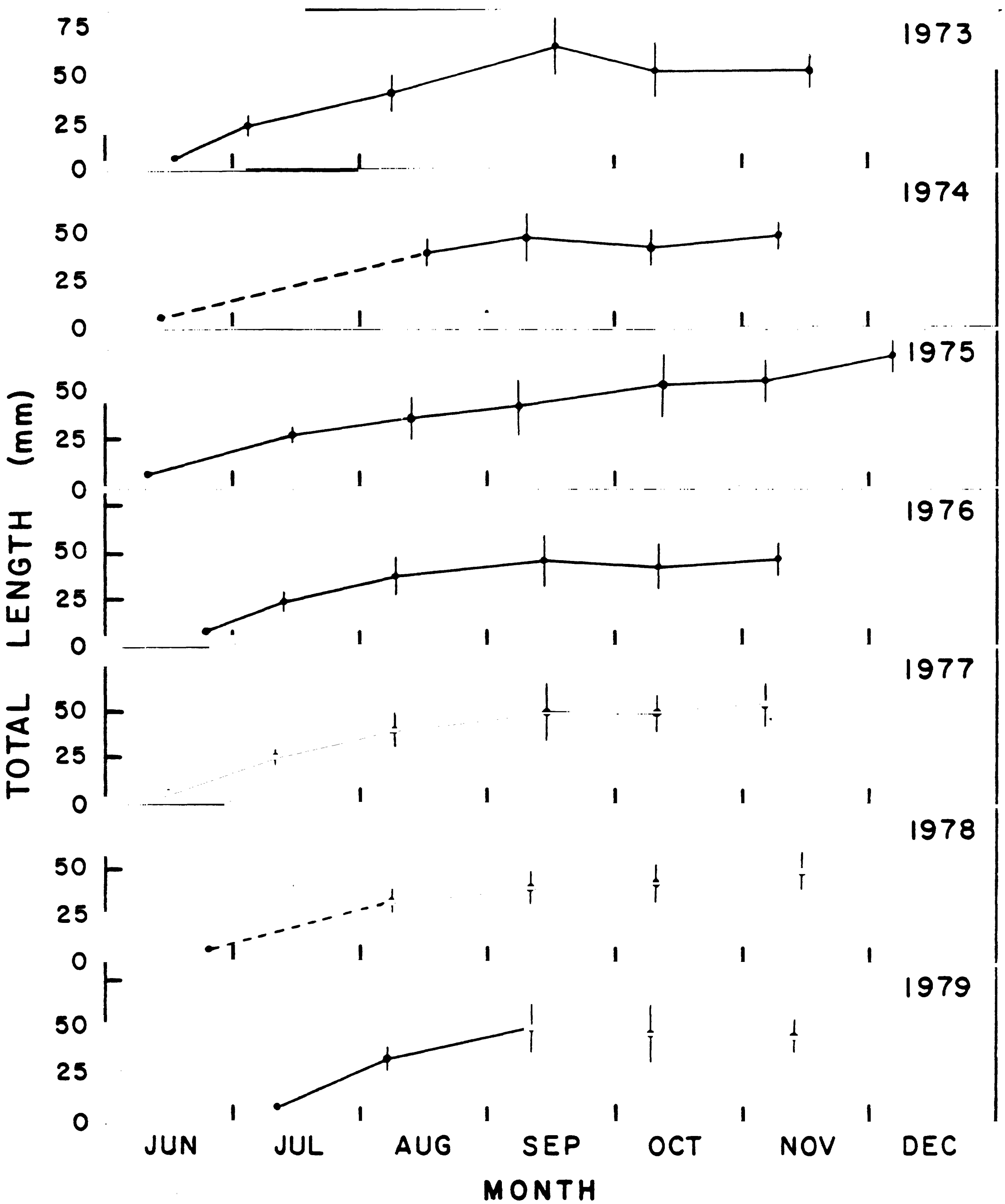


Fig. 13. Mean total length (± one standard deviation) of young-of-the-year alewives caught during 1973-1979 in Cook Plant study areas, southeastern Lake Michigan. Fish were collected with plankton nets in June and with standard series trawls, gill nets, and seines from July to December.

have resulted from offshore migration of larger YOY during October. Wells (1968) caught larger YOY alewives (66 to 74 mm) in water 21 to 32 m and smaller YOY (51 to 56 mm) in water 6 to 20 m in November. Due to the presence of several cohorts of YOY, monthly growth rates of YOY from July to November cannot be determined accurately from YOY samples.

Yearlings--Yearlings (70-80 mm) were less abundant than adults and YOY in our study area (Fig. 12). In Lake Michigan, most yearlings live offshore in mid-water until the third summer of life (Wells 1968, Brown 1972). A portion of yearling populations migrated inshore during spring and were caught in trawls and gill nets along with adults. Yearlings were collected from April to July every year during 1973-1979. Annual catches of yearlings ranged from 50 in 1979 to 3,500 in 1974.

Mean lengths of yearlings ranged from 77 to 98 mm during April (Fig. 14). Brown (1968) reported comparable mean lengths (83-89 mm) for yearlings collected in April 1967 in eastern Lake Michigan. During May, mean lengths of yearlings were 86 mm in 1974, 101.7 mm in 1975, and 90.5 mm in 1976. Because yearling growth in Lake Michigan does not start until late June (Brown 1972), mean length of yearlings caught from April to mid-June of a particular year reflected the growth of YOY during the previous summer and fall. Smaller yearlings during spring 1974 (Fig. 14) may be related to great abundance of YOY in 1973, while larger yearlings in spring 1975 may result from smaller populations of YOY in 1974 (Fig. 12). Small size of yearlings collected during June 1977 and 1978 may be related to relatively high abundance of YOY during 1976 and 1977, respectively (Figs. 12 and 13). These data suggest that YOY growth was negatively correlated with abundance. Lower growth rates of YOY during 1973 and 1974 than during 1975-1978 (Fig. 13) were, therefore, not related to plant operation.

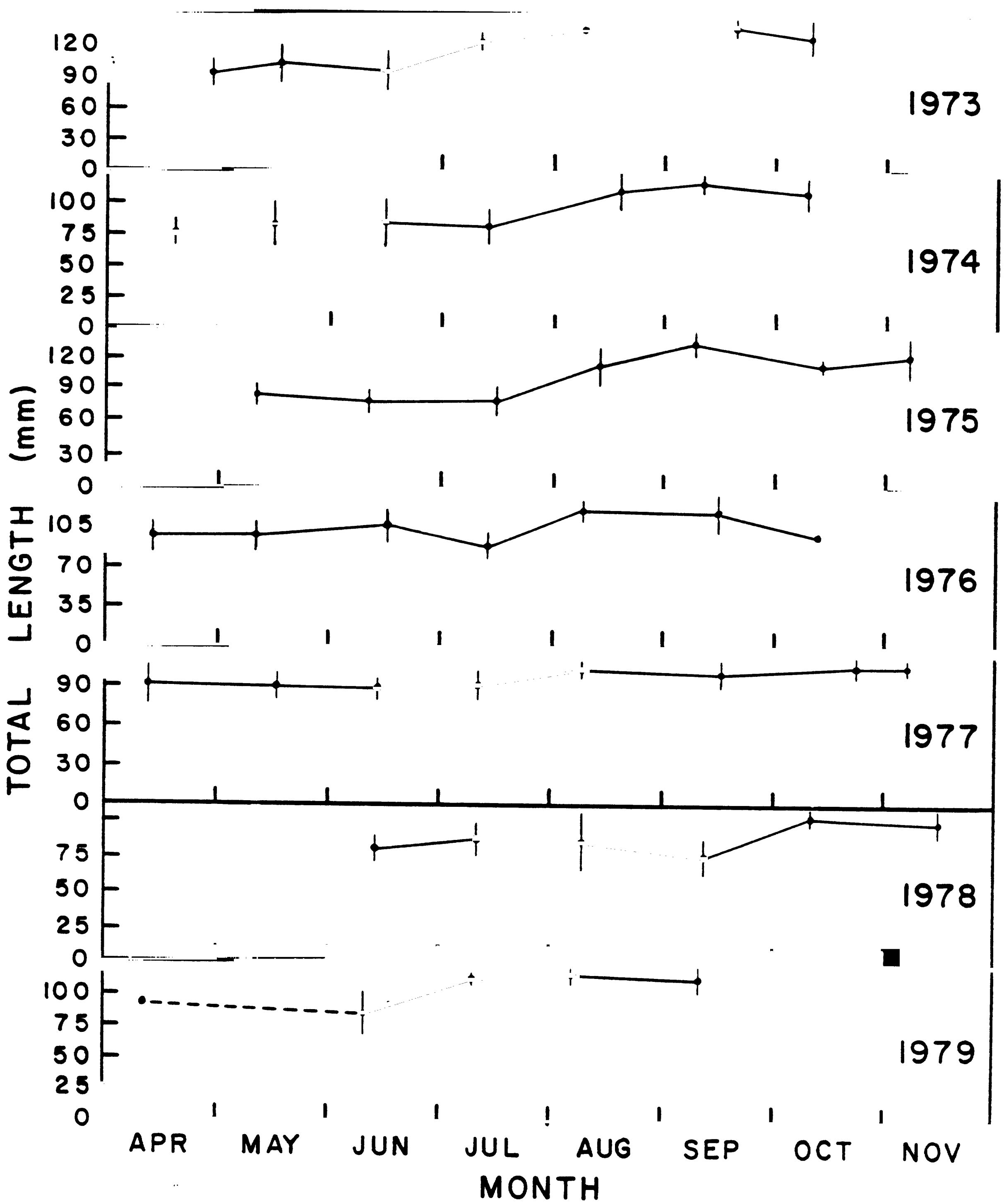


Fig. 14. Mean total length (± one standard deviation) of yearling alewives caught during 1973-1979 by standard series trawling, gillnetting, and seining in Cook Plant study areas, southeastern Lake Michigan.

Because most yearlings remained offshore through the second summer of life, there was probably little impact of plant operation on their abundance and growth.

Adults--Adult alewives including 2-year-old and older fish migrated inshore during spring. They were most abundant in the study area from April through June and were scarce after July (Fig. 12). Adults we collected were 135 to 250 mm with a modal length from 160 to 180 mm. Based on age-length data of Lake Michigan alewives (Brown 1972), 160- to 180-mm fish are 3 to 5 years old. Our data agree with Brown (1968) who reported alewives collected in eastern Lake Michigan during spring inshore migration had an average age of 3.6 years. Most age-2 alewives (approximately 110-130 mm) were immature in the spring and early summer. They remain in midwater (Brown 1972) and were, therefore, not vulnerable to our sampling gear. Modal length of adult alewives was approximately the same from April to July for most years during the study period (Fig. 12), suggesting that little growth took place during spring and early summer. A similar size composition of adult alewives was observed during preoperational and operational years, suggesting that plant operation had no effects on adult populations. Annual catches of adult alewives generally declined during 1973-1979, with large catches (25,300) in 1973 and small catches (4,000) in 1977 and 1979. As previously mentioned, the decrease in adult catches was related to lakewide decline in alewife abundance. There was no correlation between adult and YOY abundances in the study area. A high abundance of adult alewives produced high numbers of YOY in 1973 and relatively low numbers of YOY in 1974. Low abundance of adults was followed by small catches of YOY in 1978 and large catches of YOY in 1979.

Temperature-catch Relationships--

Alewives were found in water temperatures of 1-27°C, but most occurred in temperatures of 11 to 23°C (Fig. 15). These data agree with Wells (1968) who found alewives in temperatures from 8 to 22°C. Alewives displayed a size-dependent temperature relationship in which younger fish occurred in warmer water than older fish. YOY 25-65 mm were caught mostly in water temperatures of 19 to 26°C and adults 140-250 mm were found in water temperatures of 6 to 14°C (Fig. 16). These data agree with those of Brandt et al. (1980) who found YOY alewives in water 17-20°C and adults in temperatures of 11 to 14°C. Otto et al. (1976) also reported YOY prefer higher temperatures than adults.

Wells (1968) reported that the inshore migration of adults during spring is related to the warming trend of the lake. Adult alewives prefer water temperatures of 21°C in spring (Otto et al. 1976), which suggests that adults might be attracted to the discharge area in spring. No increase of adult catches was, however, observed in the plume area of the Cook Plant during 1975-1979. During spring and summer, alewives generally avoided cold water. Small catches during April 1975, 1978, and 1979 may be related to low water temperatures (1.3-8.7°C). Emery (1970) reported that alewives in Georgian Bay, Lake Huron, moved away from upwelled cold water. In Lake Michigan, Wells (1968), however, indicated that alewives were the least affected species when cold water upwelling occurred.

Catches of YOY may also be influenced by water temperature. YOY were generally abundant during summer. Smaller catches of YOY during August 1974 than August 1973 may in part be due to an upwelling of cold water (8.5-12°C) which reached the beach zone during the August 1974 sampling period. YOY migrate offshore during fall. Relatively high catches of YOY in the beach zone

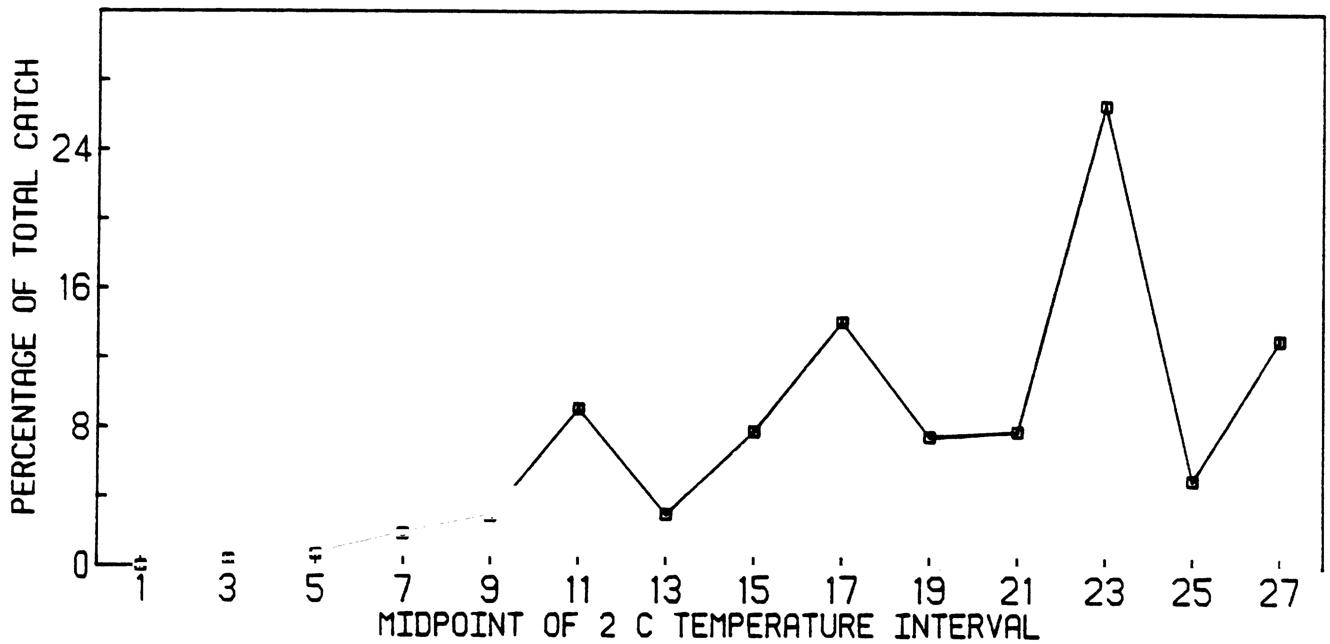


Fig. 15. Percentage of the combined total standard series catch of alewives collected during 1973-1979 from various temperatures in Cook Plant study areas, southeastern Lake Michigan.

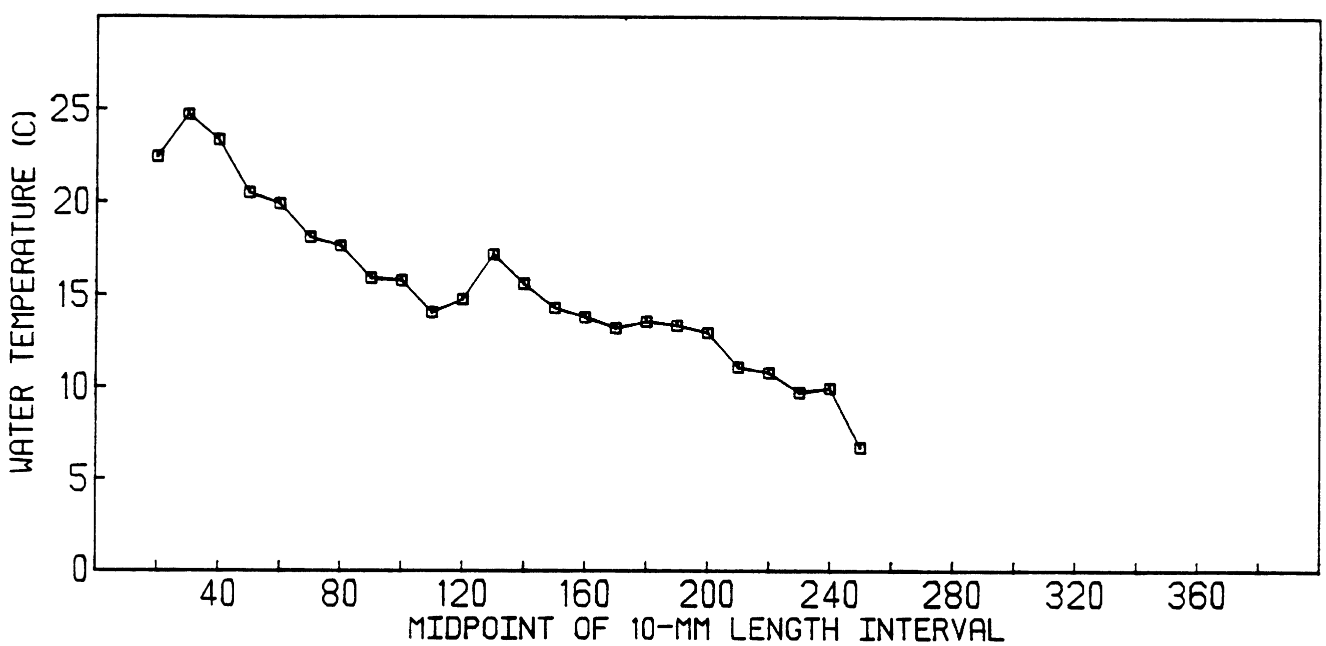


Fig. 16. Mean temperature at which different sizes of alewives were caught during 1973-1979 by standard series trawling, gillnetting, and seining in Cook Plant study areas, southeastern Lake Michigan.

during October 1975, 1978, and 1979 (Fig. 12) were probably due to relatively high water temperatures (14.7-18°C).

Other Considerations--

In Lake Michigan alewives spawn from May to August (Norden 1967, Edsall 1970, Brown 1972). In our study area spent adults were found from April to October (Table 17). Gonad data (Table 17) and fish larvae data indicated that most spawning took place in June and July. Substantial numbers of ripe alewives were caught during spring (April, May) in 1973, 1974, and 1976. Ripe alewives were, however, less common during spring 1975, 1977, 1978, and 1979 (Table 17). This decrease in abundance of spawners may in part be related to the general decline of alewife populations. Low water temperatures in spring during 1975, 1977, 1978, and 1979 may also delay inshore migration during these years.

Alewife die-offs have been reported for many areas in Lake Michigan (Brown 1972, Jude et al. 1980). In our study area, dead alewives were found on the beach from May to July every year during the study period. The number of dead alewives observed was approximately the same during preoperational and operational periods. These data suggest that alewife die-off was not caused by plant operation.

The ANOVA showed that catches in trawls, gill nets, and seines were higher during the day than at night. Alewives are known to exhibit diel vertical migration, being near the bottom during the day and near the surface at night (Graham 1956, Brandt et al. 1980). Catches were greater during the day than at night because our sampling gear fished near the bottom. Surface gill nets set in eastern Lake Michigan near the J. H. Campbell Plant captured more alewives at night than during the day (Jude et al. 1980).

Table 17. Number of ripe and spent alewives caught by standard series trawling, gillnetting, and seining in Cook Plant study areas, southeastern Lake Michigan, 1973-1979. F = female, M = male, ND = no data.

Year	Sex	Gonad condition	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	F	Ripe	9	251	178	190	124	0	0	0	0	0
		Spent	0	0	1	42	20	36	6	1	0	0
	M	Ripe	13	128	137	191	80	0	0	0	0	0
		Spent	0	0	0	232	165	59	29	3	0	0
1974	F	Ripe	3	27	127	128	196	2	1	0	0	0
		Spent	0	2	5	3	16	33	1	0	0	0
	M	Ripe	0	20	144	311	168	0	0	0	0	0
		Spent	0	4	4	3	41	69	5	2	0	0
1975	F	Ripe	0	1	25	26	29	5	0	0	0	0
		Spent	0	0	1	12	20	3	1	0	1	0
	M	Ripe	0	0	19	84	12	0	0	0	0	0
		Spent	0	0	3	35	26	10	5	0	0	0
1976	F	Ripe	0	2	104	121	135	4	0	0	0	ND
		Spent	0	0	3	6	25	7	0	0	0	ND
	M	Ripe	0	10	102	91	43	0	0	0	0	ND
		Spent	0	0	0	3	20	1	0	0	0	ND
1977	F	Ripe	0	1	28	68	63	4	0	0	0	0
		Spent	0	0	1	12	16	13	1	0	0	0
	M	Ripe	0	0	13	127	51	0	1	0	0	0
		Spent	0	0	0	24	52	9	2	0	0	0
1978	F	Ripe	ND	0	3	87	28	7	0	0	0	ND
		Spent	ND	0	0	10	0	16	1	0	0	ND
	M	Ripe	ND	0	0	215	14	2	0	0	0	ND
		Spent	ND	0	0	24	3	37	0	0	0	ND
1979	F	Ripe	ND	4	0	64	43	7	0	0	0	ND
		Spent	ND	0	0	2	37	24	0	0	0	ND
	M	Ripe	ND	0	0	68	72	5	0	0	0	ND
		Spent	ND	0	0	1	45	32	0	0	0	ND

Alewife is the most important forage species of salmonid in Lake Michigan. This species was found in the stomachs of lake, brown, and rainbow trout, coho and chinook salmon, yellow perch, rainbow smelt, burbot, channel catfish, northern pike, and alewife. Alewife is a zooplankton feeder, though larger individuals may also feed on the benthic amphipod, Pontoporeia (Scott and Crossman 1973, Morsell and Norden 1968). Alewives evidently had a great impact on several native species in Lake Michigan. Decrease of lake whitefish, lake herring, bloater, and emerald shiner in the Great Lakes is thought to be caused by extremely high alewife abundance (Smith 1968). Increased abundance of bloater in Lake Michigan during the late 1970s may be related to the decline of alewife abundance.

Bloater

Introduction--

All coregonids, except lake whitefish under approximately 300 mm in length, could not be identified to species because of morphometric changes in Lake Michigan populations and possible hybridization of some species (Smith 1964, Scott and Crossman 1973). We concluded that most small coregonids we caught were bloaters, *Coregonus hoyi*, but some of these fish may have been young lake herring, *C. artedii*, or hybrid coregonids. In previous reports (Jude et al. 1975, 1979) we referred to these fish as "unidentified coregonids," but in keeping with present practices of fishery biologists we will identify these fish as bloaters.

During preoperational years 1973 and 1974, 126 and 225 bloaters, respectively, were caught and thus this species was categorized as common in the study areas. However, in 1978 and 1979, over 1,000 bloaters each year were caught, and therefore we now classify *C. hoyi* as an abundant species. Bloater was the fifth-most abundant species in 1979.

The bloater population in Lake Michigan has changed considerably since 1900. After 1900, the population began to increase as the other seven deepwater coregonids began to decline due to overfishing and sea lamprey predation (Smith 1964). In the early 1960s, bloaters were very abundant while the other species were extremely scarce (Smith 1964). By the late 1960s, however, changes in sex, age composition, and growth of bloaters indicated the possible start of a population decline in Lake Michigan (Brown 1970). Brown's prediction proved accurate as the population declined drastically in the early 1970s, resulting in total closure of the commercial fishery in 1976 (Great Lakes Fishery Commission 1979, 1980). This action apparently came in time to reverse the population decline, in at least southeastern Lake Michigan, as evidenced by our increased catches in 1978 and 1979 and results of Crowder and Magnuson (1982).

During most months, bloaters are in water deeper than 18 m in Lake Michigan, but some fish move shoreward (to 9 m) during summer (Jobes 1949, Wells 1968). Therefore, most adult bloaters are distributed deeper than our study areas, and we are only sampling fringes of the population. Most bloaters we did catch were collected during summer, especially during upwelling of cold water when some fish move close inshore. Also, most bloaters in the study areas during summer were yearlings, while during fall some YOY were collected; very few adults (age 2+) were collected.

Total standard series catches of bloaters in the study areas ranged from 49 fish in 1975 to 3,009 fish in 1979 (7-yr mean = 734 fish). Trawls, the most productive gear, accounted for an average of 612 fish per year while gill nets and seines averaged, respectively, 46 and 76 fish per year. As a result of small and sporadic monthly catches from 1973 to 1977, catch data could not be parametrically tested. However, nonparametric statistics were employed on the trawl data.

Trawl Data--

Years--The Kruskall-Wallis test showed catches among years to be significantly different (Table 18); but the catch in preoperational years was not significantly different from the catch in operational years. The large catches in 1978 and 1979 undoubtedly caused catches among years to be significantly different. Nemenyi's pairwise comparison test showed the catch in 1978 and 1979 was significantly larger than the catch in either preoperational or the other operational years. The large catches in recent years are indicative of the bloater population increase in southeastern Lake Michigan apparently resulting from closure of the fishery.

Areas--The Kruskal-Wallis test showed no significant differences between area catches (Table 18). This finding coupled with the nonsignificance between preoperational and operational years leads to a conclusion that the Cook Plant had no detectable impact on the bloater population surveyed by trawls.

Total catches among stations also showed the increased catches in 1978 and 1979 occurred at both areas (Table 19). During other operational years

Table 18. Results of the Kruskal-Wallis test (nonparametric ANOVA) applied to 1973-1979 bloater trawl catch data from Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df	H statistic	Attained significance
Station (G, H, C, D, R)	4	5.5463	0.2357
Area (Warren Dunes, south Cook, north Cook)	2	1.7815	0.4103
(Warren Dunes, Cook Plant)	1	1.0925	0.2959
Year (1973-1979)	6	67.2690	0.0000*
(1973-74, 1975-79)	1	0.4919	0.4831
(1973-74, 1975-78, 1979)	2	16.7230	0.0002*
(1973-74, 1975-77, 1978-79)	2	21.2710	0.0000*
(1973-74, 1975-77, 1978, 1979)	3	62.7840	0.0000*
Replicate (1st haul, 2nd haul)	1	0.0144	0.9043
Depth (6 m, 9 m)	1	3.8849	0.0487*
Time (day, night)	1	2.7725	0.0959*

* Significant (P <0.1).

and preoperational years, total catches were similar between areas. Station catches, however, show that the large catches in 1978 and 1979 were proportionally greater at the two Warren Dunes stations than at Cook Plant stations. Future data should reveal if this trend, which could be a result of plant operation, continues.

The addition of station R (6 m, north Cook) to the sampling scheme in 1975 also did not document any changes attributable to plant operation (Table 19). Total catches at station R during high abundance years 1978 and 1979 were larger than at the south Cook 6-m station but still smaller than at Warren Dunes.

Table 19. Number of bloaters trawled at standard series stations and station R in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years. ND = no data.

		6-m stations			9-m stations	
		Cook Plant				
		North	South	Warren Dunes	Cook Plant	Warren Dunes
Year	Time period	R	C	G	D	H
1973	Day	ND	1	12	9	16
	Night	ND	0	4	16	5
1974	Day	ND	28	14	29	30
	Night	ND	5	30	16	11
1975	Day	1	6	4	5	6
	Night	2	8	8	0	9
1976	Day	5	11	6	36	8
	Night	1	1	0	3	0
1977	Day	48	50	38	31	18
	Night	13	10	4	14	4
1978	Day	126	88	427	153	241
	Night	142	52	218	32	113
1979	Day	17	36	27	73	172
	Night	121	44	228	649	1,224

Gill Net Data--

Years--While trawl catches in 1978 and 1979 showed a dramatic increase, gill net catches, as in previous years, remained small. This disparity between the two gear types resulted from gill nets not sampling bloaters less than 115 mm in length. All large catches in 1978 and 1979 were yearlings and YOY, most of which were less than 134 mm in length when caught. It also appears that few adult bloaters enter the shallow study areas, and thus gill net catches remained small.

Total gill net catches did not show any differences among years which could be attributed to plant operation (Table 20). There was a tendency, during all study years, for greater catches at 9-m than at 6-m stations, undoubtedly because of bloater preference for deeper, colder water.

Areas--Examination of total catches revealed no differences between areas. This finding coupled with the lack of change in catch between preoperational and operational years leads to a conclusion that the Cook Plant had no detectable effect on the bloater population sampled by gill nets.

Examination of trends after addition of the north Cook stations in 1975 also showed no changes or trends in catch attributable to plant operation. Total catches were in general similar to those at Warren Dunes stations and at the south Cook stations.

Seine Data--

Until 1979, very few bloaters were seined (Table 21). Small catches in the beach zone indicated bloater preference for deeper, colder water, while the large catch in 1979 corroborated the recent population increase. Ninety-one percent of the seined fish in 1979 were collected in one September haul at station A (north Cook). This unusual inshore occurrence of YOY bloaters indicates the population increase may be quite substantial, and it further indicates the contagious distribution of YOY in the beach zone. Overall, seine catches were too small and sporadic to draw any conclusions regarding plant effects.

Summary of Operational Effects--

Gill net and seine catches were too small and sporadic to analyze statistically, but examination of total catches indicated no changes or trends

Table 20. Number of bloaters gillnetted at standard series stations and stations R and Q in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years. ND = no data.

		6-m stations			9-m stations		
		Cook Plant			Cook Plant		
		North	South	Warren Dunes	North	South	Warren Dunes
Year	Time period	R	C	G	Q	D	H
1973	Day	ND	0	1	ND	1	11
	Night	ND	0	3	ND	19	27
1974	Day	ND	1	0	ND	12	2
	Night	ND	23	2	ND	11	9
1975	Day	0	0	0	0	0	0
	Night	0	0	0	0	0	2
1976	Day	0	0	4	1	10	4
	Night	0	3	0	14	13	5
1977	Day	21	1	4	8	5	7
	Night	9	10	1	18	11	10
1978	Day	1	2	0	2	1	3
	Night	12	15	20	34	10	11
1979	Day	3	0	1	12	6	0
	Night	2	2	0	13	30	10

in distribution or abundance of bloaters which could be attributed to plant operation. Nonparametric statistical analysis of the trawl data also showed no changes attributable to plant operation. Field catches did reveal a population increase in 1978 and 1979 which was unrelated to plant operation. Trawl catches further showed a proportionally larger catch at Warren Dunes than at the Cook Plant during these 2 years; this trend, if it continues, may indicate a possible plant effect.

Table 21. Number of bloaters seined at standard series stations in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

		Cook Plant stations		
		North	South	Warren Dunes station
Year	Time period	A	B	F
1973	Day	0	1	0
	Night	0	0	0
1974	Day	0	2	0
	Night	0	0	0
1975	Day	1	0	0
	Night	0	0	0
1976	Day	3	0	0
	Night	0	0	0
1977	Day	7	1	1
	Night	0	0	0
1978	Day	1	3	2
	Night	0	0	0
1979	Day	472	23	12
	Night	0	0	0

Distribution and Growth by Age-Group--

Bloaters spawn from mid-January to mid-March and larvae hatch from mid-May to mid-July in southeastern Lake Michigan (Wells 1966). Young-of-the-year usually were not collected by us until September (Fig. 17). Most yearlings and adults (age 2+) were collected in summer during upwelling of cold water. Yearlings constituted 69% of the total catch while YOY and adults comprised, respectively, 25% and 6%.

Young-of-the-year--Little is known about the spatial and temporal distribution of YOY bloaters in the Great Lakes. Wells (1966) found most

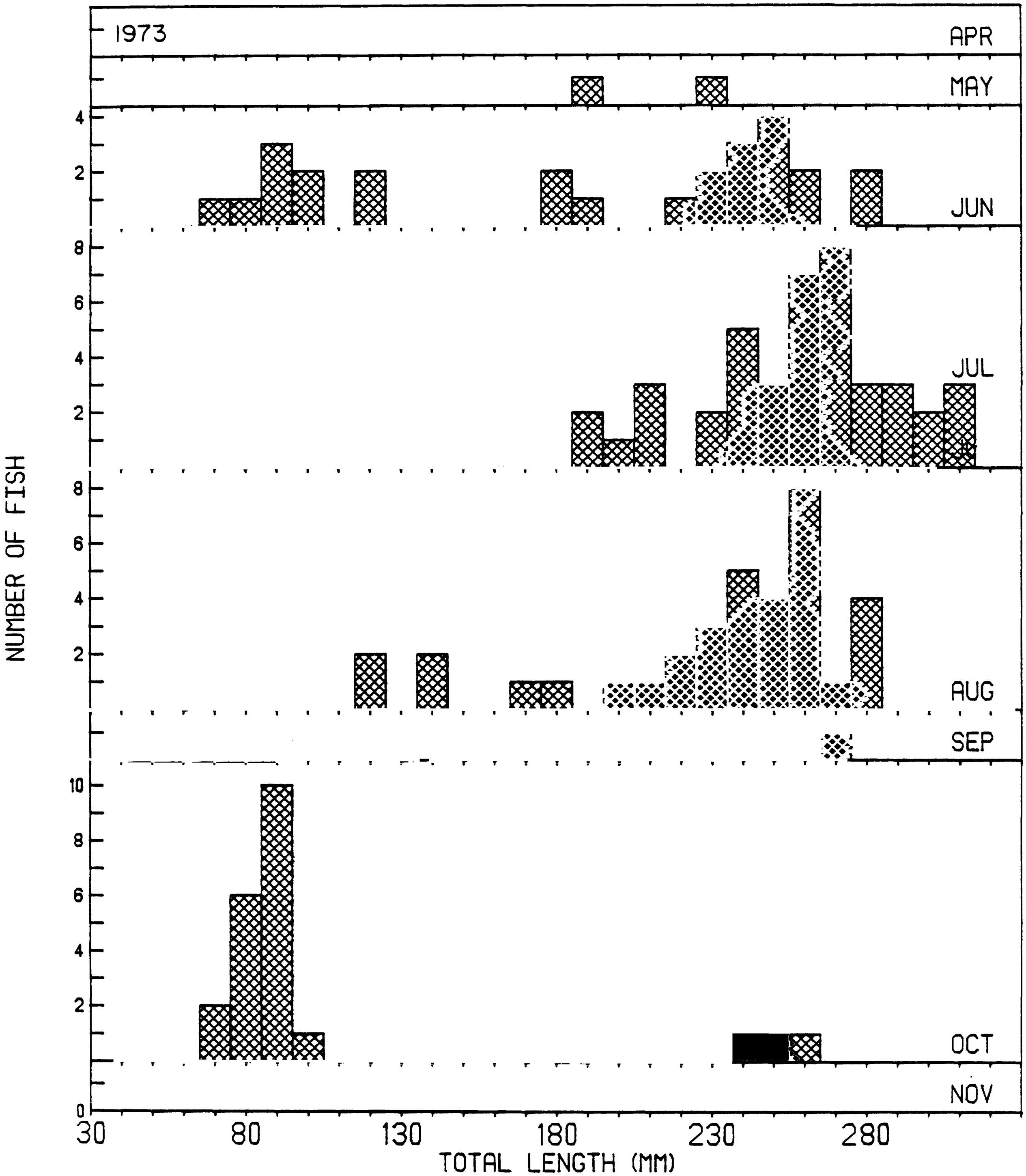
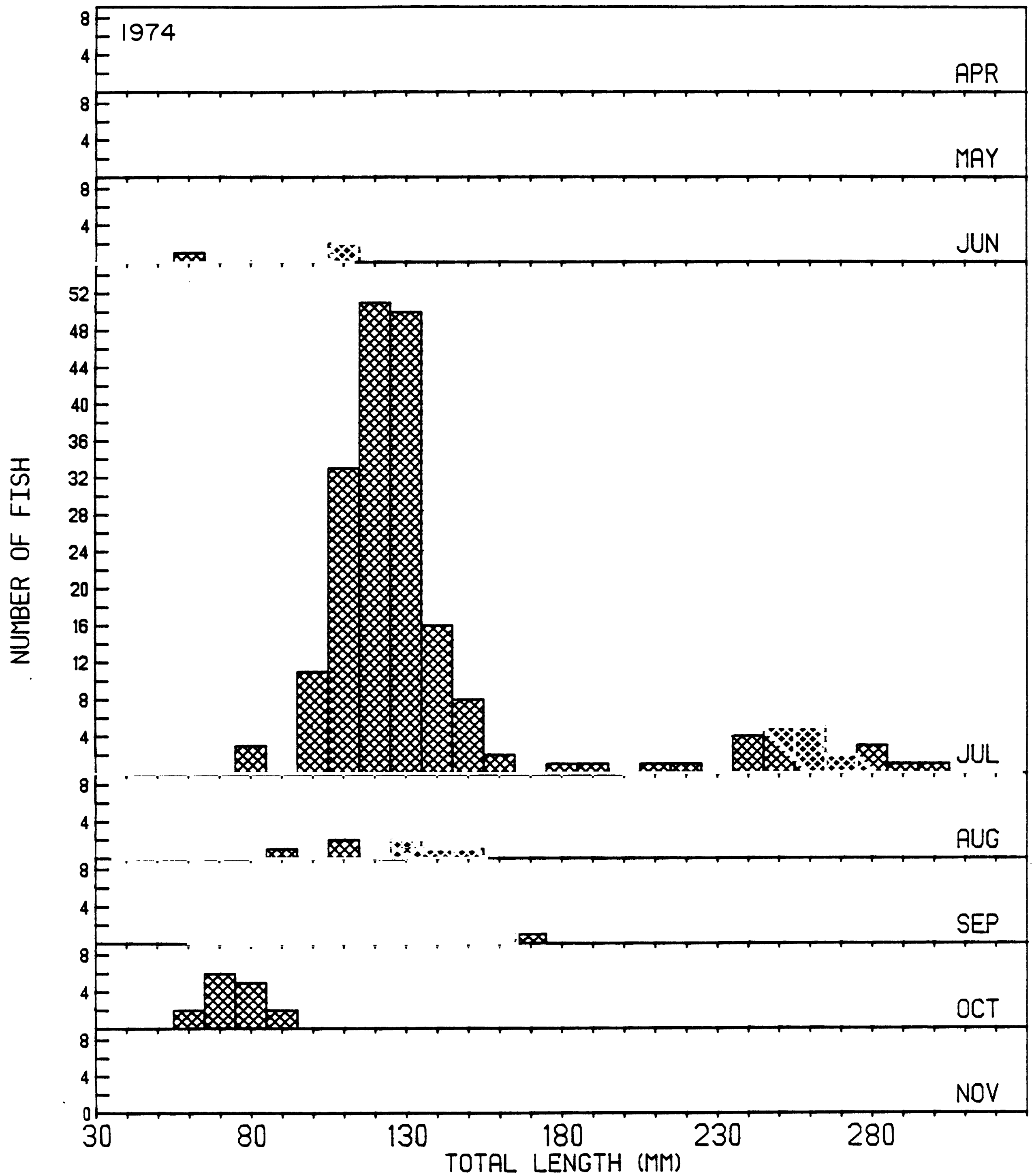


Fig. 17. Monthly length-frequency histograms of bloaters caught during 1973-1979 by standard series trawling, gillnetting, and seining in Cook Plant study areas, southeastern Lake Michigan.



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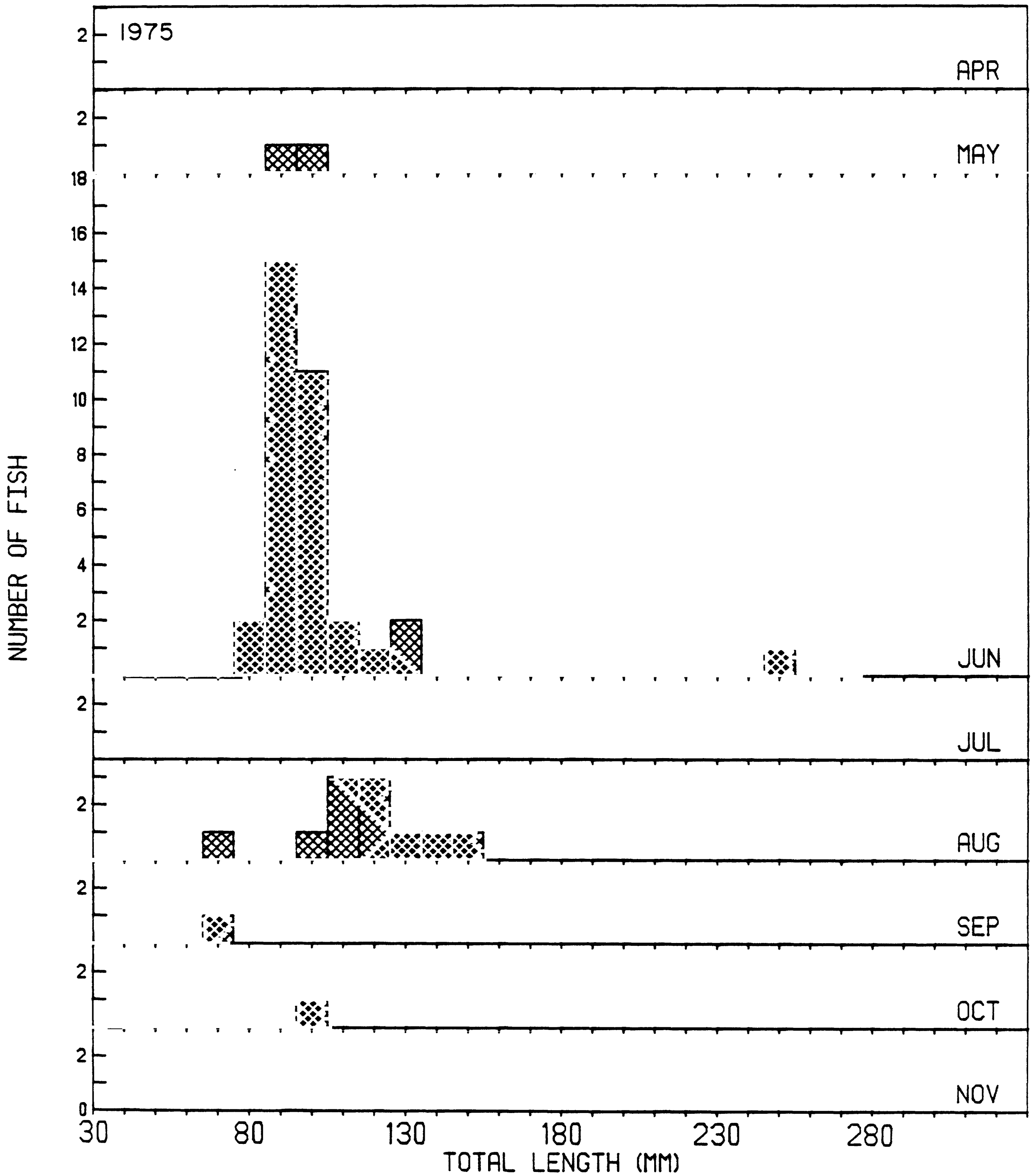

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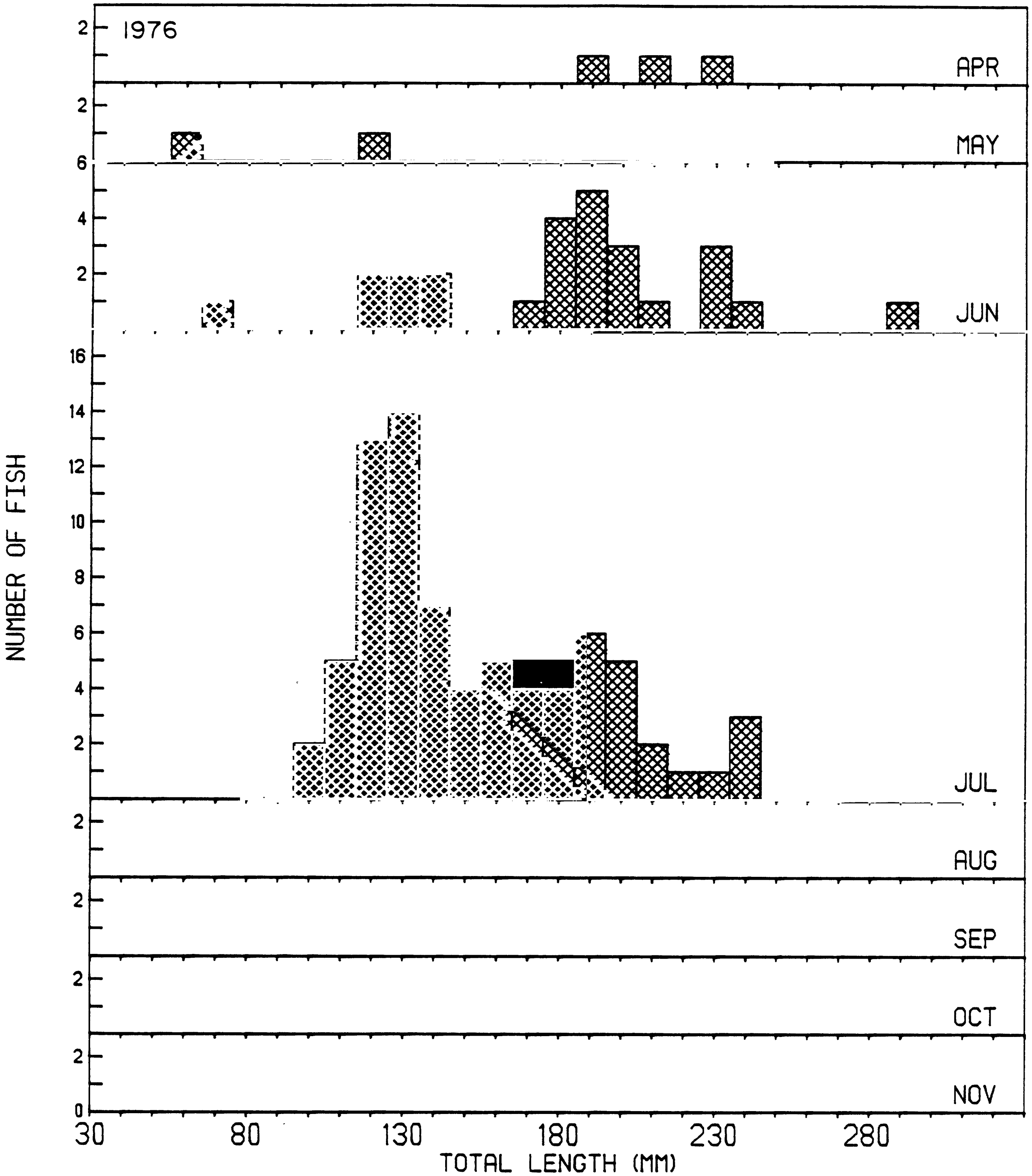

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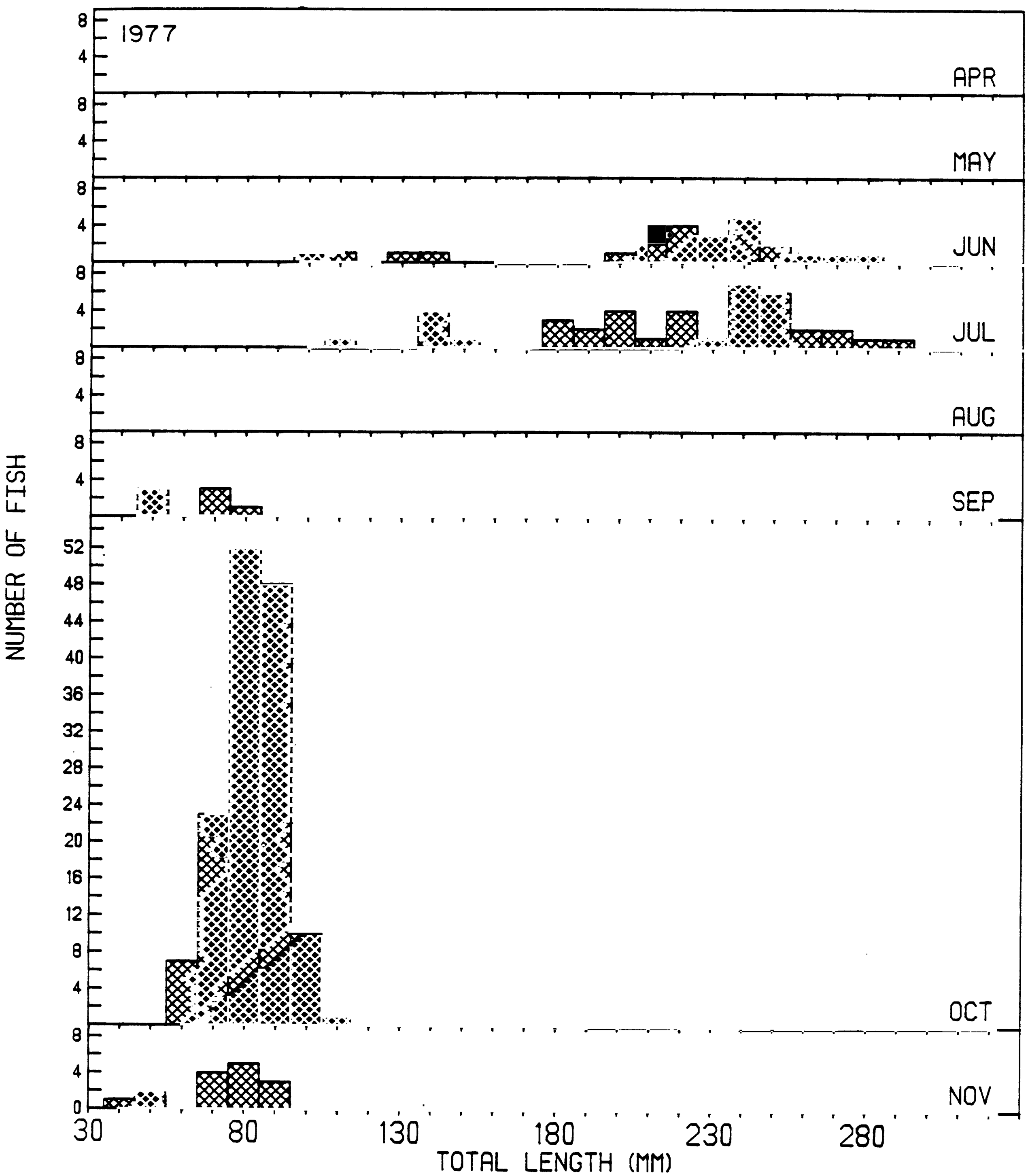

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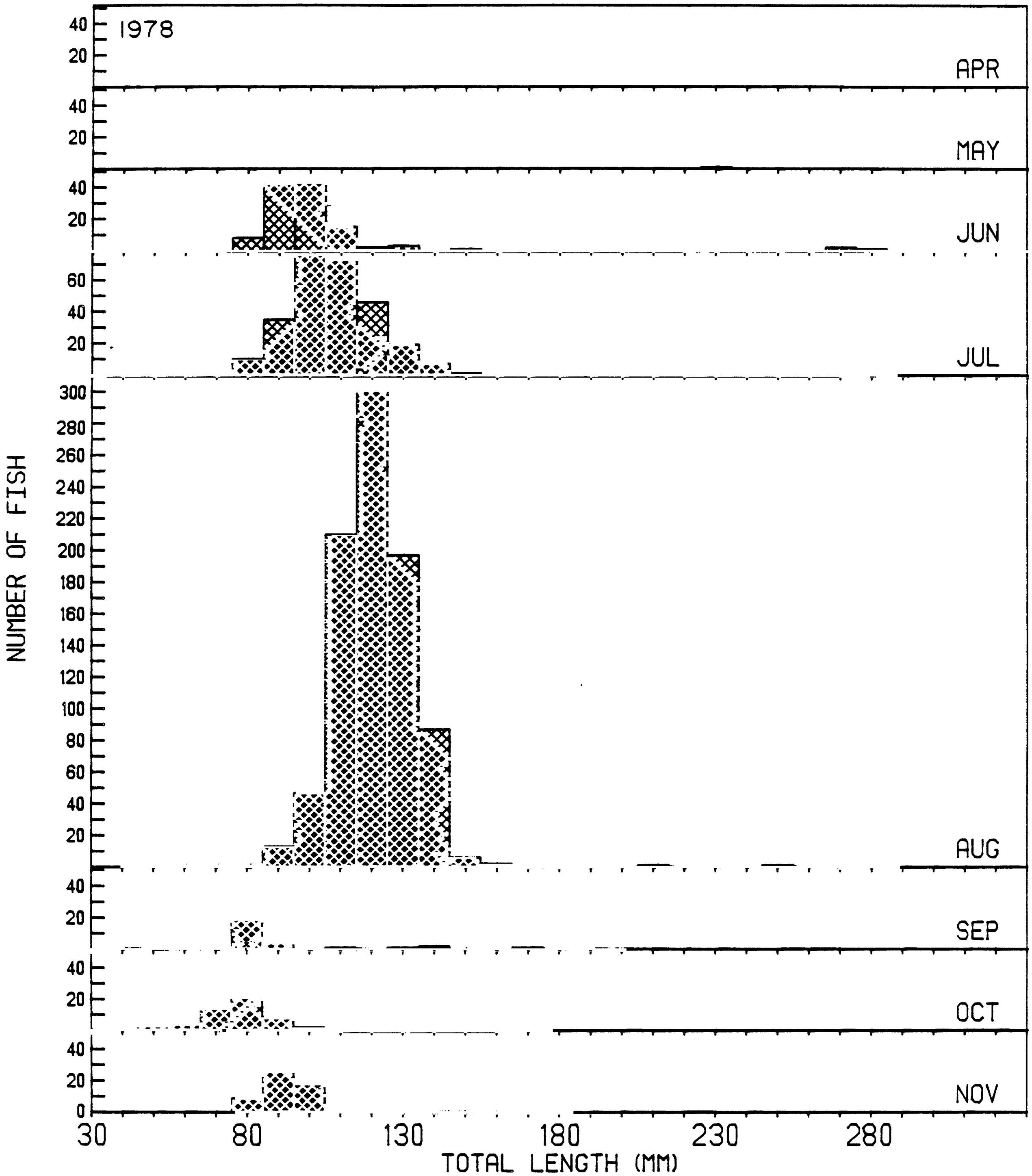

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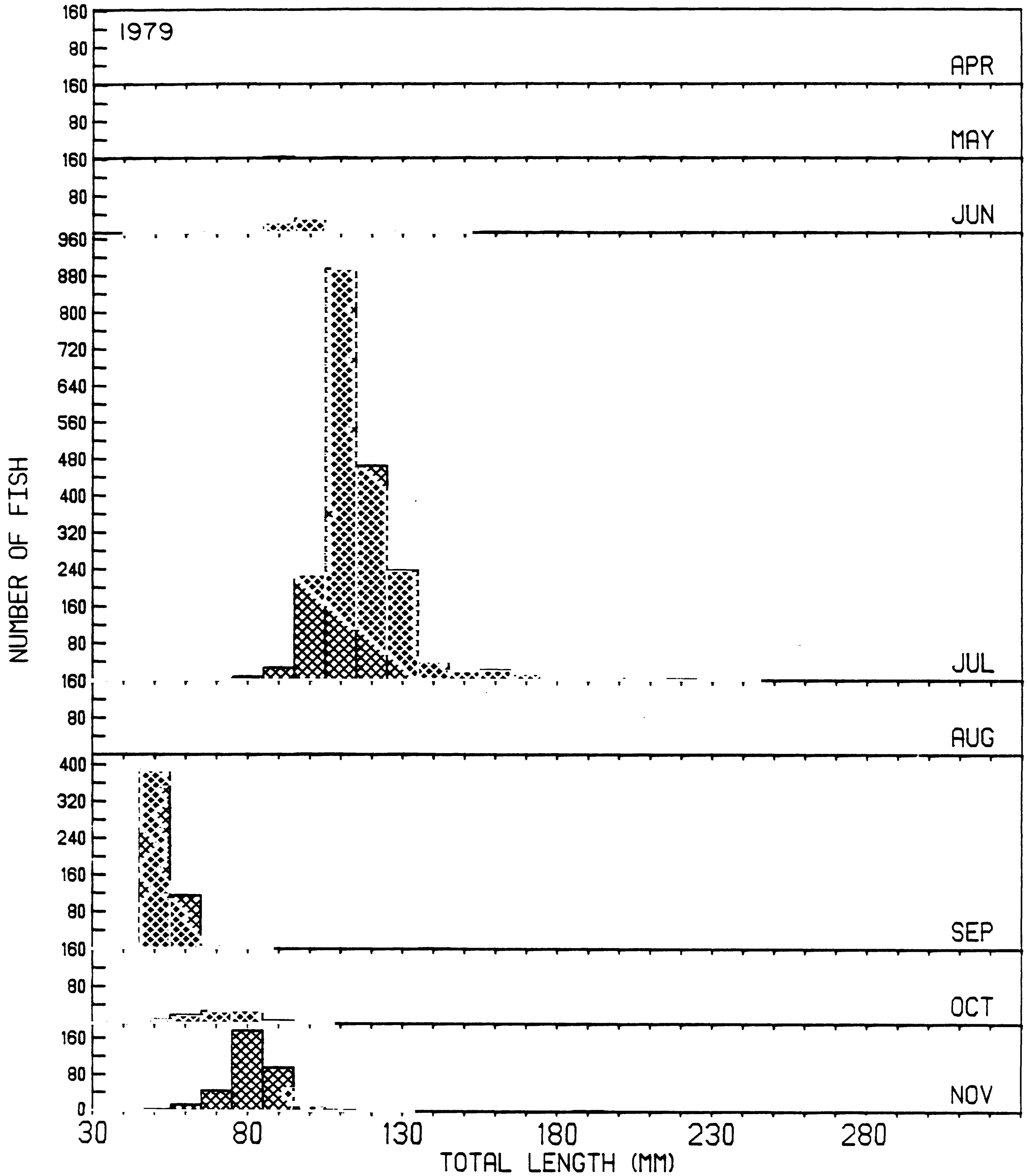


Fig. 17. Continued.

larvae near bottom at 70-100-m depths of southeastern Lake Michigan; however, he could not capture YOY greater than 15 mm in length. Wells also found no evidence of a shoreward movement. We collected YOY at 6 and 9 m from September to November and occasionally in August (Fig. 17). Also in September and October 1979, YOY were seined at 1-m depths. Whether most YOY moved shoreward in the fall or fringes of the population were distributed inshore could not be determined.

During most years, YOY were at a modal length of 80 mm with a range of 35 to 117 mm. Growth of these YOY appears to be somewhat slower than bloater growth reported by other investigators. As determined from scale-back calculations, during the first year of life YOY bloaters reach approximately 90-100 mm in Lake Michigan (Jobes 1949, Wells 1966, Brown 1970), in Lake Ontario (Stone 1944), and in Lake Superior (Dryer and Beil 1968). Assuming that average length was 11 mm on July 1 (Wells 1966), YOY we collected grew an average of 0.65 mm/day.

Yearlings--Yearlings were usually collected from June to August during periods of upwelling. Occasionally, yearlings were collected in May and September (Fig. 17). The effects of upwelling were demonstrated by June to August trawl data which showed that while 39% of all samples were collected when water temperatures were above 18.4°C, only 1% of the 3,501 bloaters were caught at these temperatures. Presumably, yearlings followed the thermocline as it moves shoreward during upwelling. Wells (1968) indicated that juvenile bloaters live off bottom in the thermocline, and Crowder and Magnuson (1982) also commonly found yearling bloaters in the metalimnion. These findings suggest that yearlings we collected inshore were near bottom where the thermocline intersects the bottom.

Yearlings collected in spring were usually at modal lengths of 90-100 mm. By July and August, yearling modal lengths had increased to 120-130 mm. At the end of their second year, bloaters in the Great Lakes are approximately 145-155 mm (Stone 1944, Jobes 1949, Dryer and Beil 1968, Brown 1970). Considering that yearlings we collected in July and August had not finished their second year's growth and YOY did not attain average lengths reported from other areas, it appears that yearling growth was above average in the study area.

Adults--Only 290 adults (age 2+) were collected over the 7-year period. Like yearlings, most adults were collected in summer when they followed the inshore movement of cold water during upwelling. Dryer (1966) and Wells (1968) found that adult bloaters moved shoreward to 18 m and occasionally shallower during summer in the Great Lakes. While Wells found adults moving offshore during fall in Lake Michigan, Dryer found adults still inshore during fall in Lake Superior. Our data agree with the seasonal distribution reported by Wells, with bloaters moving to extremely shallow water only during upwelling in summer, and offshore in fall. An additional finding from our summer seine catches is that when cold water reaches the shoreline, some bloaters also will move to the shoreline.

Temperature-catch Relationships--

Most bloaters were caught at temperatures from 6 to 19.9°C (Fig. 18). The catch at 23°C resulted from an unusual catch of 463 YOY in one September 1979 seine haul. Wells (1968) found that during summer adult bloaters were most abundant from 6 to 10°C, while Crowder and Magnuson (1982) found yearlings and adults most abundant at 5 to 16°C in southeastern Lake Michigan. The warmer temperatures from which we collected bloaters may be related to

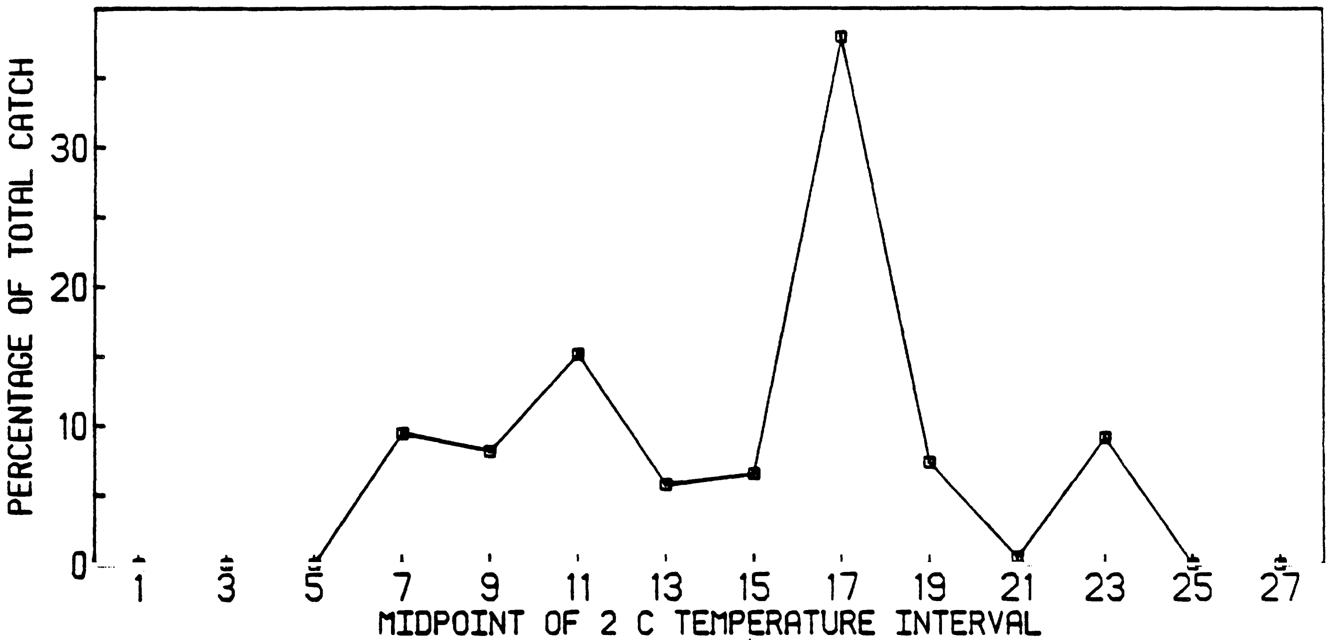


Fig. 18. Percentage of the combined total standard series catch of bloaters collected during 1973-1979 from various temperatures in Cook Plant study areas, southeastern Lake Michigan.

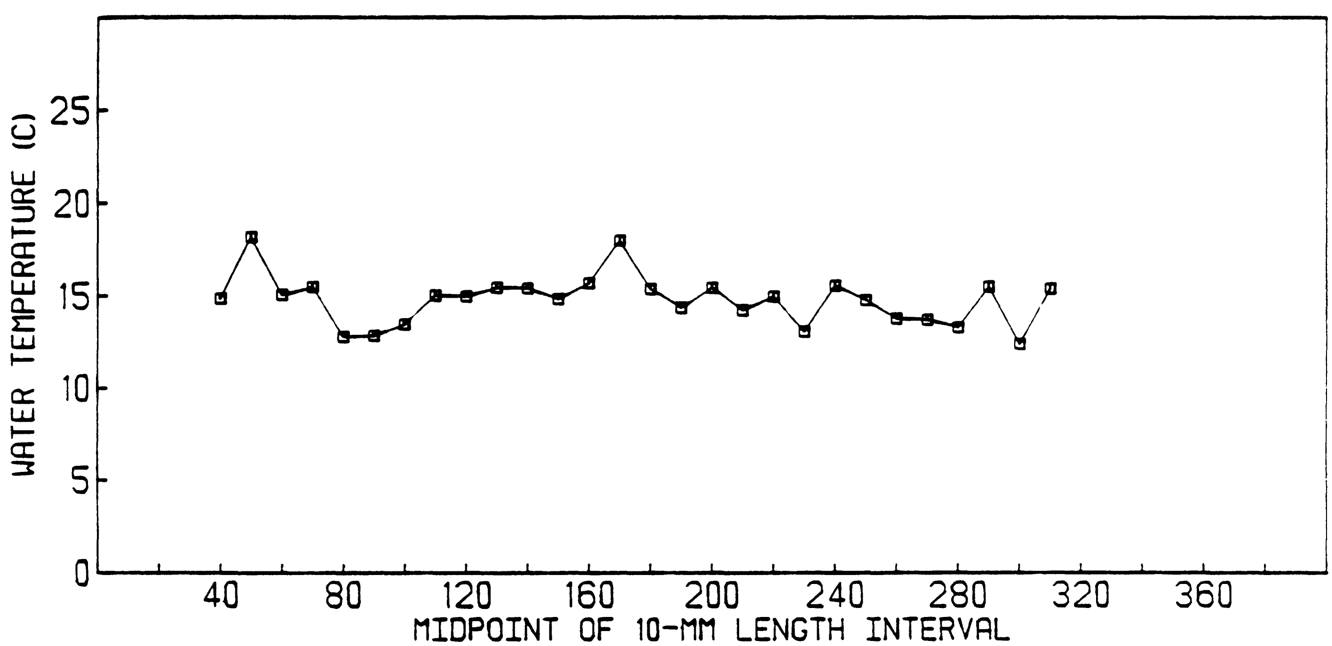


Fig. 19. Mean temperature at which different sizes of bloaters were caught during 1973-1979 by standard series trawling, gillnetting, and seining in Cook Plant study areas, southeastern Lake Michigan.

either the preponderance of juveniles, including YOY which Wells and Crowder and Magnuson did not sample, or to our samples only representing fringes of the bloater population. The major portion of the population may have been in cooler waters. However, Crowder and Magnuson (1982) did find yearlings at warmer temperatures than adults. Our data also show that small bloaters were caught at slightly warmer temperatures than large fish (Fig. 19).

Other Considerations--

Because most bloater larvae are in very deep water (Wells 1966), they should not be vulnerable to entrainment at the Cook Plant; and while juveniles and adults are also in deep water for most of the year (Wells 1968), they will be vulnerable to entrapment during their summer inshore movement. Our data show that juveniles will move to the shoreline with the thermocline during upwelling. As they pass through the 7.3-m intake depth, they may be impinged. Impingement data substantiate this, because a sizable number of bloaters, almost 22,000, was impinged in July 1968. Most of these fish were yearlings, and most were impinged during an upwelling. Impingement mortality may continue at this level because of the recent population increase in Lake Michigan.

Rainbow Smelt

Introduction--

The rainbow smelt, an introduced marine species, has become an important component of Lake Michigan's fish community since introduced in 1912 (Van Oosten 1937). This species now provides commercial and sport fisheries throughout the Great Lakes. In addition, rainbow smelt are found in the diet of several other economically important fish including walleye, yellow perch, and the salmonids (Wright 1968, unpublished data - Great Lakes Research Division). Adult smelt, in turn, feed primarily on alewives which are a

preferred prey of salmonids (O'Gorman 1974). A crustacean, Mysis relicta, and a variety of amphipods, ostracods, and aquatic insect larvae, are also consumed by rainbow smelt in the Great Lakes. In becoming one of the major species in the Great Lakes, smelt have also, presumably, depressed some native fish stocks through competition and predation. Historically, smelt and lake herring abundances have been inversely related, the declines of lake herring having been in part attributed to overt competition from smelt (Smith 1972, Christie 1974). Because smelt are piscivorous and abundant in Lake Michigan, fluctuations in the population of this species alone could potentially affect many other species in the lake.

Adult smelt inhabit deep, offshore areas of the lake for much of their life. However, they do move inshore during upwelling and for spawning. Young-of-the-year and yearlings reside in relatively shallow depths during spring through mid-summer. Standard series fishing during preoperational years showed smelt to be the third-most abundant species collected (Jude et al. 1979). Hence, smelt occupy inshore areas often enough to be susceptible to impingement, entrainment, and any plume effects. Standard series fishing during operational years also resulted in large smelt catches. These data, together with the large preoperational data base, should elucidate changes in the temporal, spatial, or thermal distribution of smelt and allow detection of any plant effects.

Trawl Data--

Trawling was the most effective method of capturing rainbow smelt in the study areas and accounted for 86.3% of the total smelt catch from 1973 through 1979. ANOVA was performed on day and night catch data from April to October. November catches were too small to be included in the analysis.

Years--ANOVA of the 1973-1979 trawl data showed the main effect Year highly significant (Table 22). Yearly catches of smelt fluctuated greatly, ranging from 738 fish in 1976 to 13,284 in 1973. Catches also varied within preoperational and operational sampling years. Following the greatest catch of smelt in 1973, the catch during 1974 dropped to 5,138. During operational years the catch was smallest in 1976 (738 fish) and largest in 1978 (8,598 fish). The results of Scheffe's test also demonstrated significant year-to-year fluctuations. Except for 1974, the catch of each year was significantly different from the mean catch of all other years. In addition, the mean catch during preoperational years was significantly larger than catches during Unit 1 operational years (1973-1974 vs. 1975-1978) and Unit 2 operational years (1973-1974 vs. 1978-1979), suggesting possible plant effects. However, this significance was attributed to the exceptionally large 1973 catch. Because catches fluctuated greatly within preoperational and operational years, any plant effects were difficult to distinguish from natural population fluctuations by examination of the variable Year. The significant Year x Month interaction established that the pattern of monthly catch differed among years. Most of this monthly variation occurred during April, May, and August (Fig. 20). In addition, disparate catches during these months accounted for the yearly fluctuation in catch. Presence or absence of large April or May catches appear to depend on whether the timing of smelt spawning (Table 23) coincided with our sampling schedule. When these events occurred simultaneously, large catches resulted. Young-of-the-year (YOY) smelt first became vulnerable to standard series fishing gear during August when they comprised the bulk of the catch. Therefore, fluctuating catches during this month were directly related to the variable year-class strength of this cohort.

Table 22. Analysis of variance summary for log(catch + 1) of rainbow smelt. Fish were trawled from April to October, 1973-1979 in Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df#	Adjusted mean square##	F-statistic	Attained significance
Year	6	12.4019	187.8836	0.0000**
Month	6	9.4430	143.0578	0.0000**
Area	1	1.6127	24.4320	0.0000**
Depth	1	9.4161	142.6495	0.0000**
Time	1	0.0173	0.2617	0.6092
Y x M	36	4.4678	67.6847	0.0000**
Y x A	6	0.1327	2.0108	0.0633
M x A	6	0.6410	9.7107	0.0000**
Y x D	6	1.1242	17.0306	0.0000**
M x D	6	0.1007	1.5250	0.1686
A x D	1	0.1418	2.1485	0.1435
Y x T	6	0.8548	12.9503	0.0000**
M x T	6	1.8350	27.7990	0.0000**
A x T	1	0.0054	0.0819	0.7749
D x T	1	2.8323	42.9081	0.0000**
Y x M x A	36	0.5014	7.5956	0.0000**
Y x M x D	36	0.6020	9.1195	0.0000**
Y x A x D	6	0.4058	6.1480	0.0000**
M x A x D	6	0.2882	4.3658	0.0003**
Y x M x T	36	1.2223	18.5177	0.0000**
Y x A x T	6	0.1275	1.9314	0.0747
M x A x T	6	0.2609	3.9530	0.0008**
Y x D x T	6	0.1269	1.9223	0.0761
M x D x T	6	0.4590	6.9532	0.0000**
A x D x T	1	0.0423	0.6403	0.4241
Y x M x A x D	36	0.1865	2.8259	0.0000**
Y x M x A x T	36	0.2076	3.1452	0.0000**
Y x M x D x T	36	0.2178	3.3000	0.0000**
Y x A x D x T	6	0.0676	1.0236	0.4094
M x A x D x T	6	0.0484	0.7332	0.6231
Y x M x A x D x T	36	0.2270	3.4394	0.0000**
Within cell error	390	0.0660		

Two degrees of freedom were subtracted from the error term to correct for two missing observations where cell means were substituted.

Mean squares were multiplied by harmonic mean cell size/maximum cell size (nh/n = 0.9949) to correct for two missing observations where cell means were substituted.

** Highly significant (P <0.001).

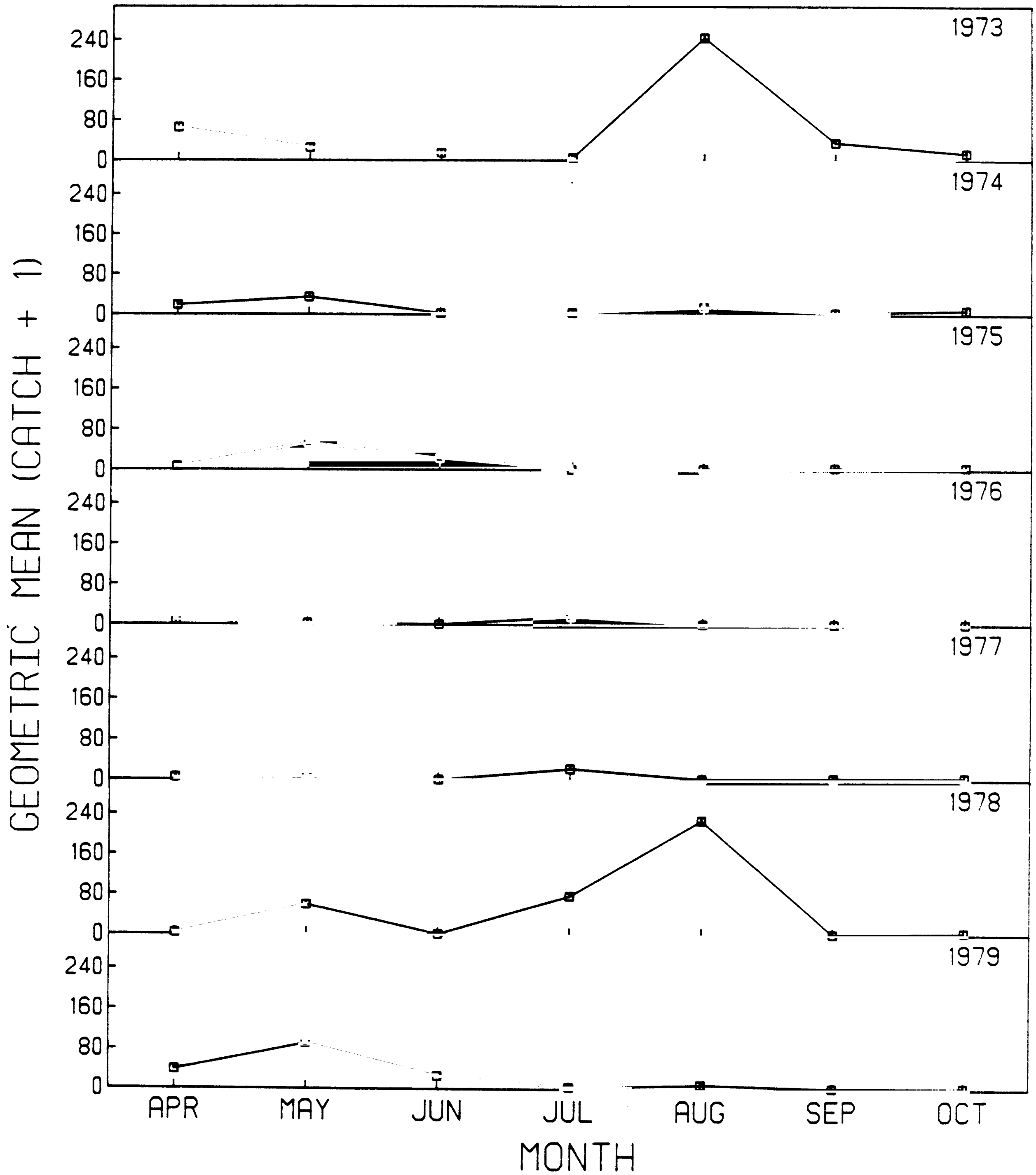


Fig. 20. Monthly geometric mean number of rainbow smelt caught by standard series trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975–1979 were operational years.

Table 23. Number of ripe and spent rainbow smelt caught by standard series trawling, gillnetting and seining in Cook Plant study areas, southeastern Lake Michigan, 1973-1979. F = female, M = male, ND = no data.

Year	Sex	Gonad condition	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	F	Ripe	25	195	3	0	0	0	0	0	0	0
		Spent	0	81	5	4	0	49	12	2	0	0
	M	Ripe	21	179	0	0	0	0	0	0	0	0
		Spent	0	42	12	2	1	28	5	0	0	0
1974	F	Ripe	14	87	0	0	0	0	0	0	0	0
		Spent	0	20	4	0	4	1	0	0	0	0
	M	Ripe	4	111	9	0	1	0	0	8	0	1
		Spent	0	3	25	1	2	6	0	0	0	0
1975	F	Ripe	12	25	3	0	0	0	0	0	0	0
		Spent	0	1	1	4	0	0	0	0	0	0
	M	Ripe	9	41	14	0	0	0	0	0	0	0
		Spent	0	0	5	3	0	0	0	0	0	0
1976	F	Ripe	8	55	0	0	0	0	0	0	0	ND
		Spent	0	56	3	7	0	0	0	0	0	ND
	M	Ripe	12	58	5	1	0	0	0	0	0	ND
		Spent	1	25	2	3	0	0	0	0	0	ND
1977	F	Ripe	0	7	0	0	0	0	0	0	0	0
		Spent	0	13	0	0	0	0	0	0	0	0
	M	Ripe	0	15	0	0	0	0	1	1	0	0
		Spent	0	2	0	0	0	0	0	0	0	0
1978	F	Ripe	ND	4	2	0	0	0	0	0	0	ND
		Spent	ND	12	62	1	3	13	0	0	0	ND
	M	Ripe	ND	4	16	0	2	1	0	2	0	ND
		Spent	ND	0	28	1	2	3	0	0	0	ND
1979	F	Ripe	ND	46	4	0	0	0	0	0	0	ND
		Spent	ND	2	16	0	0	0	0	0	0	ND
	M	Ripe	ND	26	5	0	0	1	0	0	6	ND
		Spent	ND	1	47	0	0	0	0	0	0	ND

Areas--Area was also a significant main effect because overall mean trawl catches of smelt at Warren Dunes exceeded catches at Cook (Fig. 21). However, the Year x Area interaction was not significant, reflecting a preference for Warren Dunes over the Cook Plant area rather than a plant effect. An Area x Month interaction resulted from the pattern of monthly catches differing between Warren Dunes and Cook areas. When August catches were low, catches from the two sampling areas were equally distributed. During years of large August smelt catches, Warren Dunes catches greatly exceeded those of the Cook Plant area (Fig. 21). Because August trawl catches were mostly YOY smelt, Warren Dunes may be a better habitat for YOY than Cook.

Trawl station R (6 m, north Cook) was added in 1975 to more fully assess the effects of plant operation. The 1975-1979 trawl ANOVA including station R showed Year, Month, Station, and most interactions were significant (Table 24). Scheffe's test identified the significant Station effect as the result of the mean catch at 6- and 9-m Warren Dunes stations (G,H) exceeding those at the Cook stations (C,D,R). However, there was no significant difference between the Warren Dunes and Cook 6-m stations (G vs. C,R). Catches from these stations fluctuated considerably among months. Occasionally, catches at one station greatly exceeded the others, but overall, no long-term trends were evident (Fig. 22). These results could indicate a subtle area effect of plant operation at 9-m stations. However, preoperational data showed that this probably reflected a preference by smelt for Warren Dunes trawl stations over Cook trawl stations rather than a plant effect.

Gill Net Data--

Gill net catches were too small and sporadic to analyze by ANOVA. Only 3.8% of the total smelt catch resulted from gillnetting. Instead,

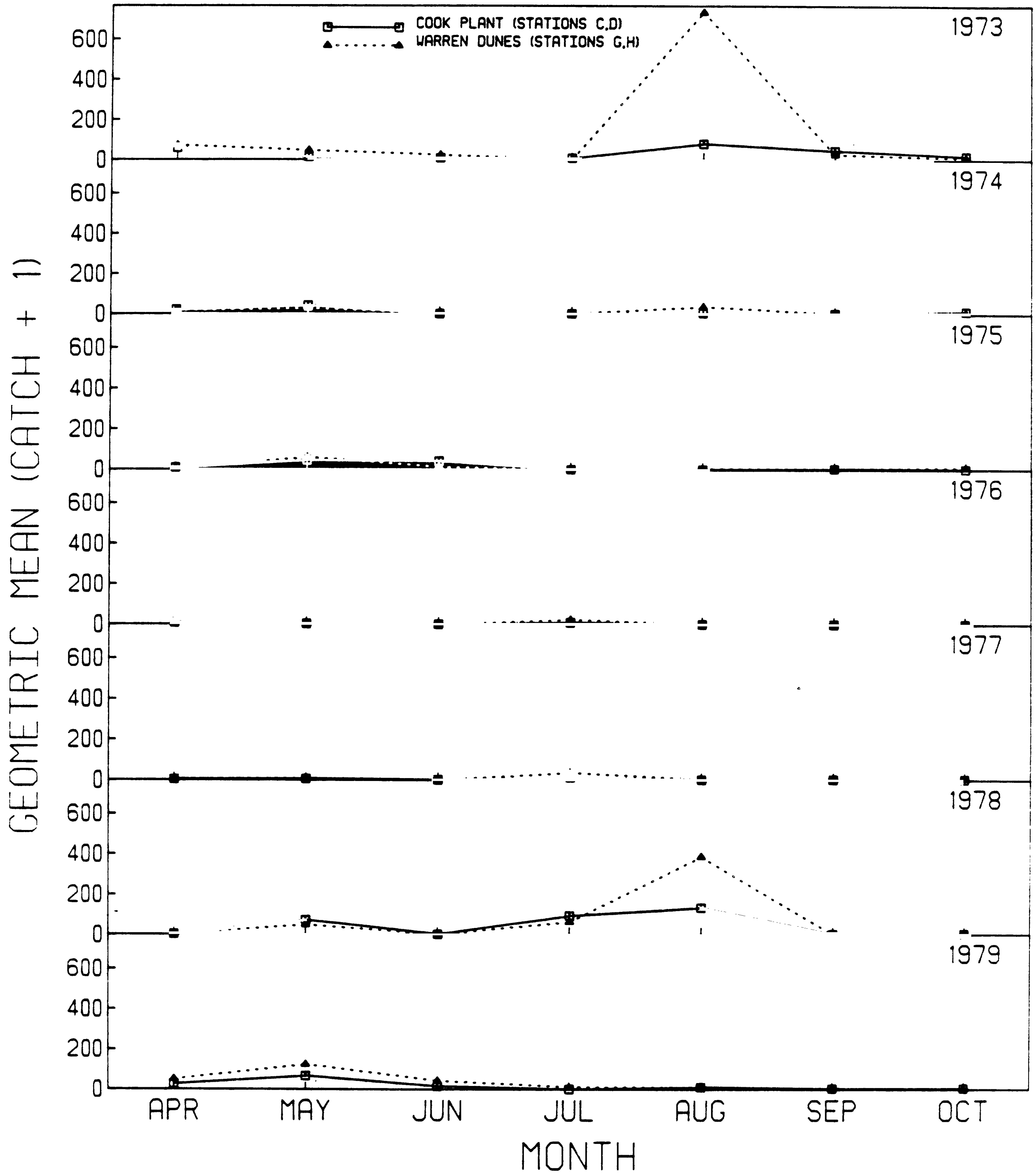


Fig. 21. Monthly geometric mean number of rainbow smelt caught by standard series trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

Table 24. Analysis of variance summary for log(catch + 1) of rainbow smelt. Fish were trawled from April to October, 1975-1979 in Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df	Mean square	F-statistic	Attained significance
Year	4	12.4091	183.5288	0.0000**
Month	6	8.9307	132.0841	0.0000**
Station	4	1.0826	16.0120	0.0000**
Time	1	0.3771	5.5768	0.0188
Y x M	24	6.6088	97.7439	0.0000**
Y x S	16	0.3399	5.0274	0.0000**
M x S	24	0.3346	4.9480	0.0000**
Y x T	4	0.6213	9.1895	0.0000**
M x T	6	2.7823	41.1506	0.0000**
S x T	4	0.7008	10.3640	0.0000**
Y x M x S	96	0.2689	3.9771	0.0000**
Y x M x T	24	1.0312	15.2519	0.0000**
Y x S x T	16	0.1081	1.5984	0.0668
M x S x T	24	0.2163	3.1991	0.0000**
Y x M x S x T	96	0.1747	2.5834	0.0000**
Within cell error	350	0.0676		

** Highly significant (P <0.001).

nonparametric analyses were employed to determine if there were significant differences among years and areas.

Gill net data showed occasional large spring catches when sampling conicided with the inshore spawning migration, and occasional large summer catches during upwelling events in June 1976 and August 1973 and 1978 (Fig. 23). This natural seasonal variability contributed to the differences between yearly catches.

Years--Results from data analyzed using the Kruskal-Wallis test found significant year differences in catch at the north (1975-1979) and south Cook areas (1973-1979). Nemenyi's test showed that smelt catches in 1975 and 1977 were significantly smaller than the large 1979 catch. Because these differ-

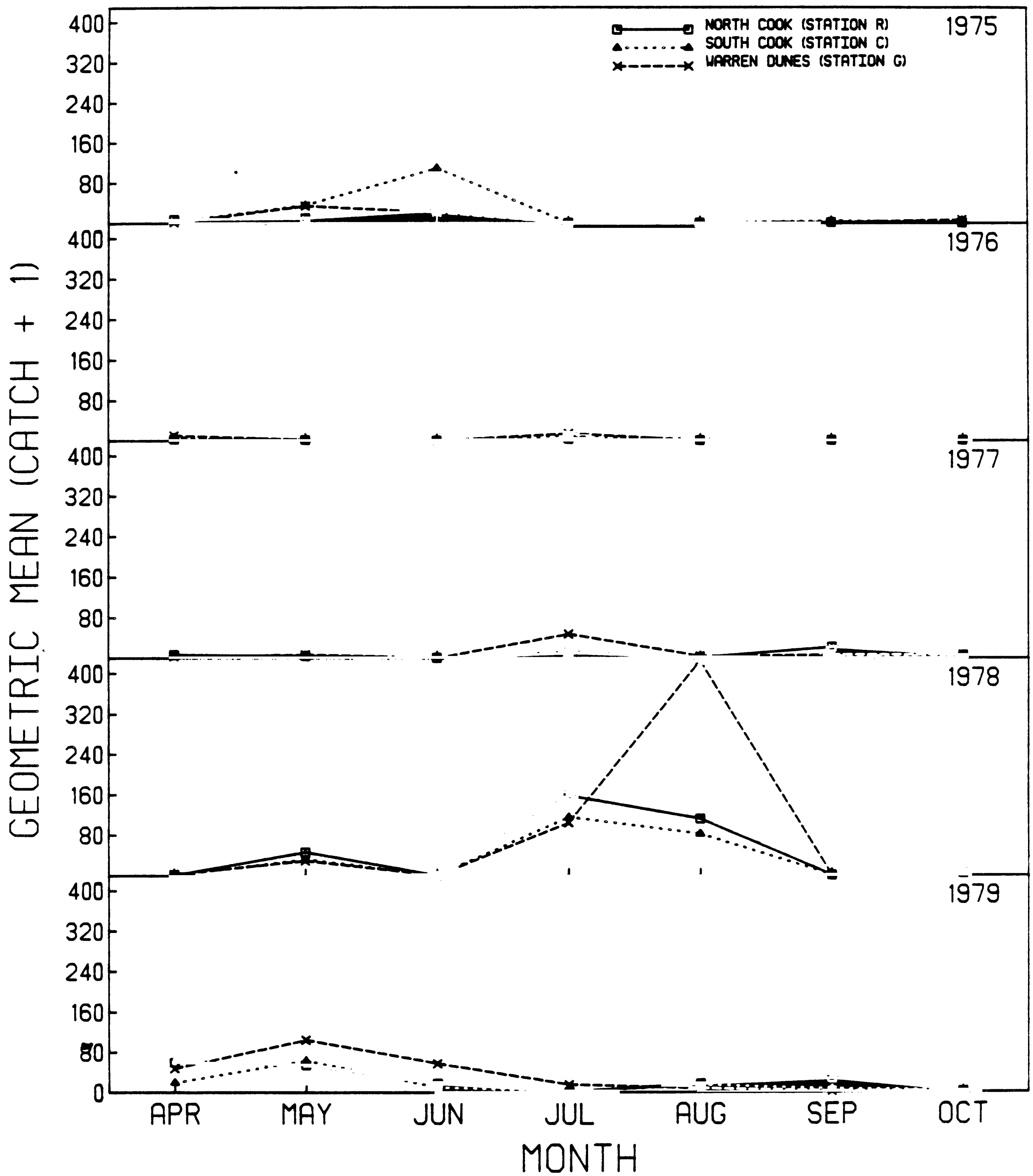


Fig. 22. Monthly geometric mean number of rainbow smelt caught during operational years 1975-1979 by standard series and station R trawling in Cook Plant study areas, southeastern Lake Michigan.

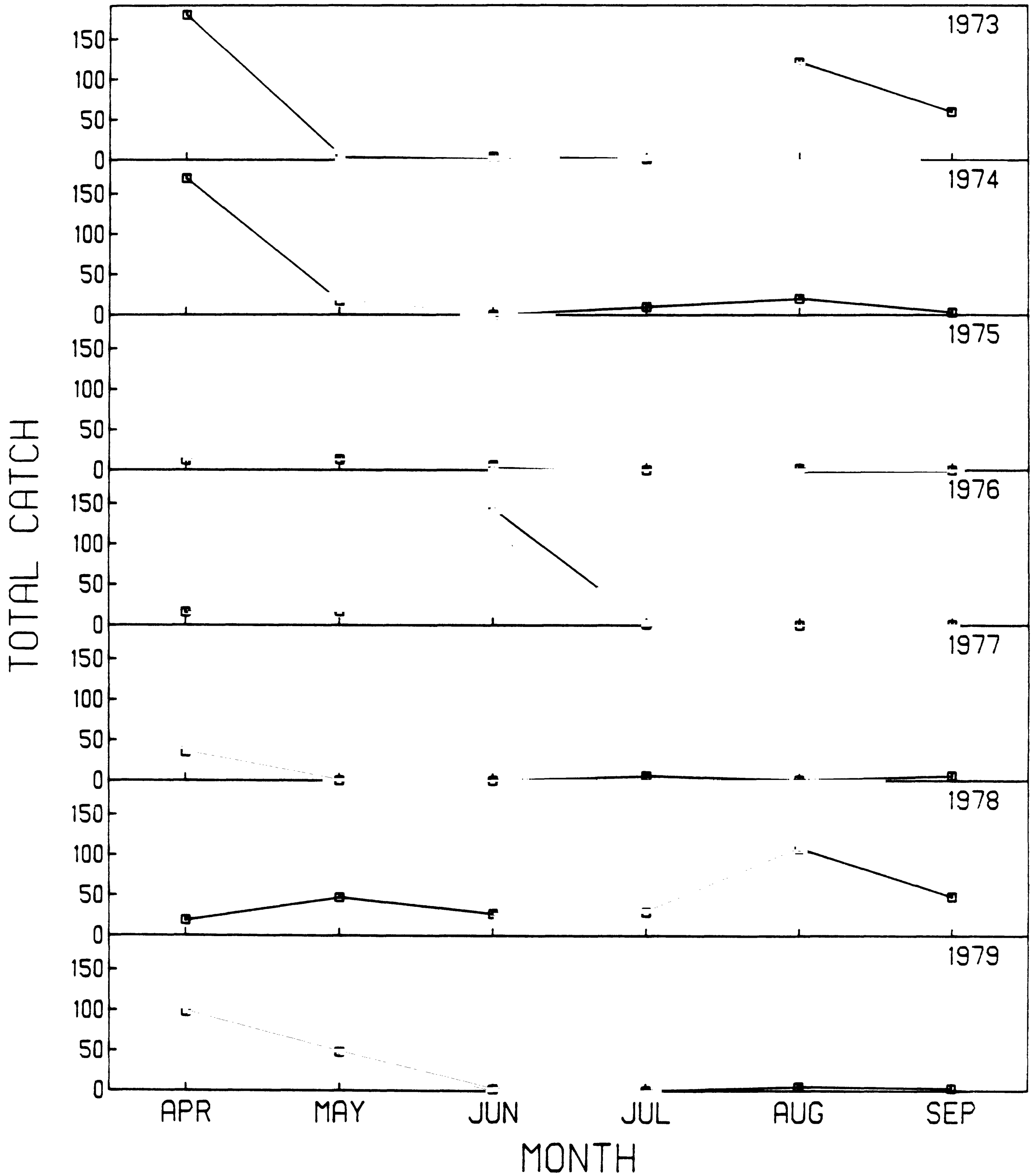


Fig. 23. Monthly total number of rainbow smelt caught by standard series gillnetting in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

ences were detected only among operational years and not between preoperational and operational years, they do not provide evidence of plant effects.

Areas--The Kruskal-Wallis test identified significant catch differences by year at the Cook areas, but not Warren Dunes. This Year x Area interaction raises the possibility of plant-related effects. However, as demonstrated by the main effect Year, the significant differences were only observed among operational years at the south Cook area (stations C and D). Total yearly catch between areas also showed no consistent pattern in preoperational or operational years (Fig. 24). During months when large catches occurred, occasionally one area produced a greater catch; but no consistency in either one area over the other or among years occurred (Fig. 25). At the north Cook area (Stations Q and R) no preoperational data exist, precluding preoper-

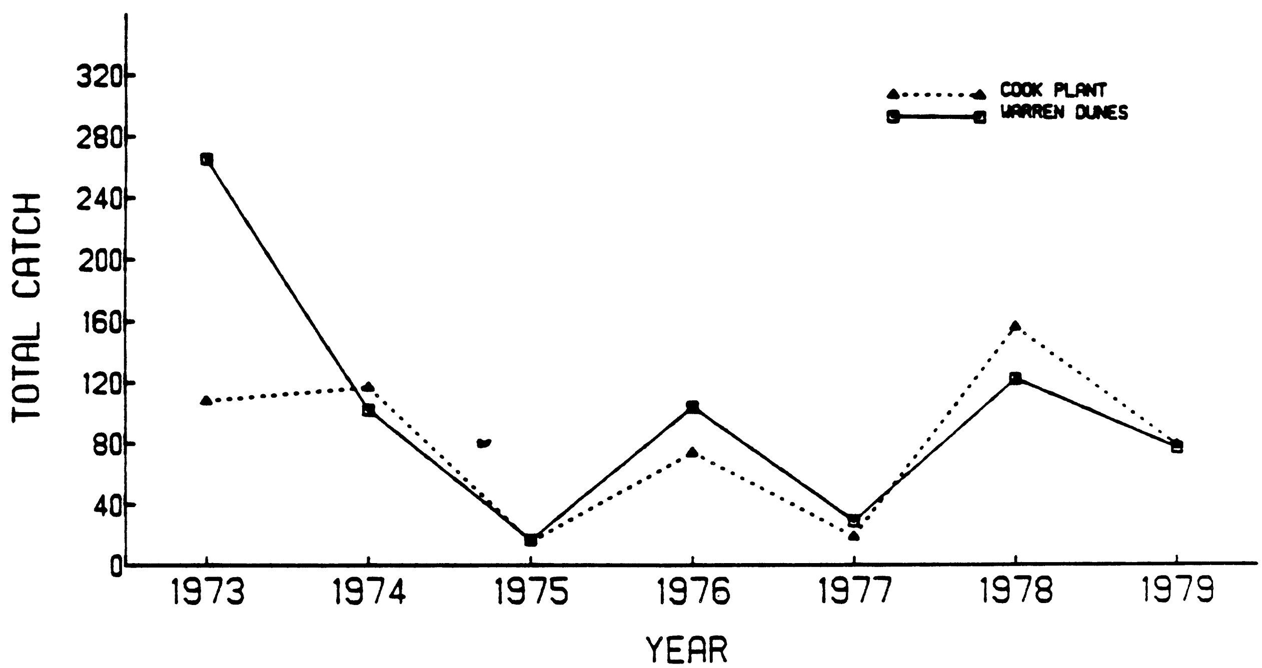


Fig. 24. Yearly total number of rainbow smelt caught by standard series gillnetting in Cook Plant study areas, southeastern Lake Michigan: 1973 and 1974 were preoperational years and 1975-1979 were operational years.

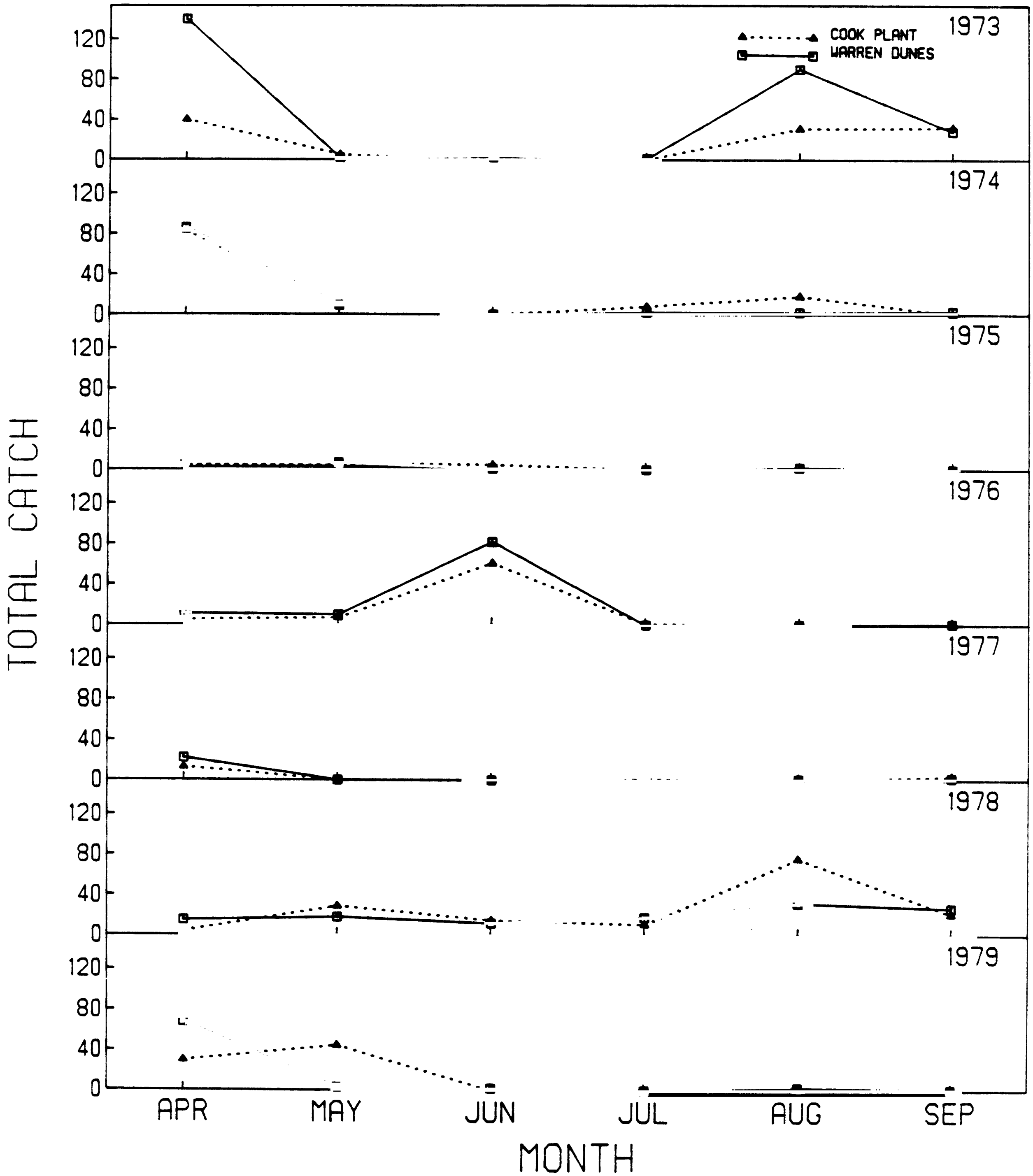


Fig. 25. Monthly total number rainbow smelt caught by standard series gillnetting in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

ational and operational comparisons. Because catches during the first full year of Unit 2 operation (1979) exceeded catches during the previous operational years, plant effects may be suggested. However, these results are inconclusive.

Gillnetting at the north Cook area (stations Q and R) allowed a comparison of catches from three areas during operational years (Fig. 26). The previously described significant differences in catch observed only among operational years did not provide evidence of plant effects. In addition, the Kruskal-Wallis test showed no significant differences in catch between the three areas during* those years. Hence, the addition of gillnetting stations Q and R did not provide any evidence of plant effects on smelt.

Seine Data--

Seining resulted in 9.9% of the smelt catch from 1974 to 1979. In addition, most of this catch was confined to April and May. Therefore, only these months were included in the seine ANOVA.

Years--ANOVA of the 1973-1979 seine data found the main effect Year significant (Table 25). Scheffe's test identified a large 1973 catch and small catches in 1977 and 1978 as most responsible for this variation. Mean catches during preoperational years were also significantly larger than catches during all operational years (1973-1974 vs. 1975-1979). However, this too seems to be the result of exceptionally large 1973 and small 1977 and 1978 catches (Fig. 27). As with trawling data, the significant Month and Year x Month interaction seemed to depend on the timing of spawning and our sampling schedule.

Areas--Mean catches among stations were not significantly different (Table 25). However, the Year x Station interaction was significant.

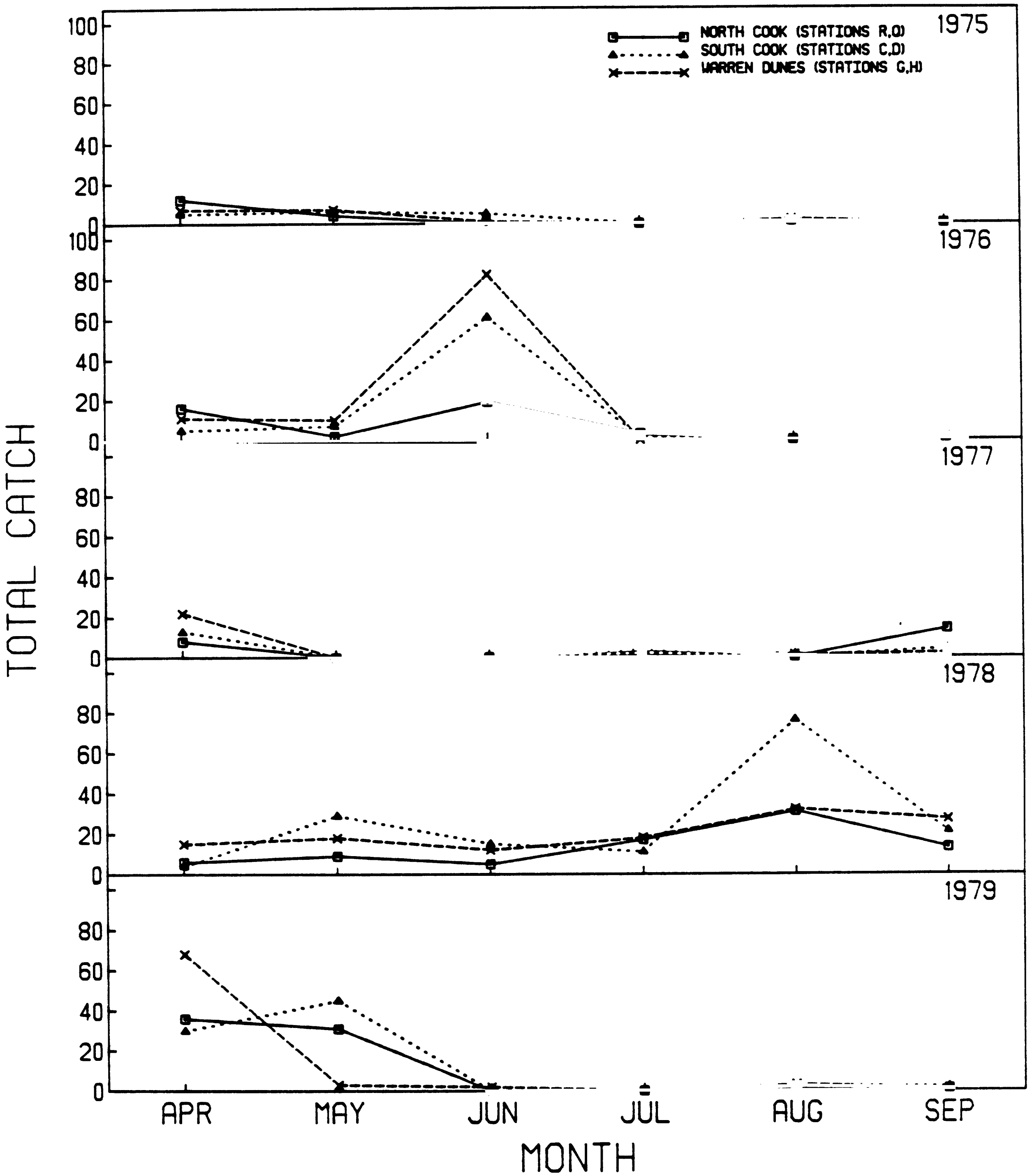


Fig. 26. Monthly total number of rainbow smelt caught during operational years 1975-1979 by standard series and stations R and Q gillnetting in Cook Plant study areas, southeastern Lake Michigan.

Table 25. Analysis of variance summary for log(catch + 1) of rainbow smelt. Fish were seined during April and May, 1973-1979 in Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df	Mean square	F-statistic	Attained significance
Year	6	2.6953	32.8359	0.0000**
Month	1	0.8797	10.7175	0.0015*
Station	2	0.1707	2.0795	0.1314
Time	1	13.5623	165.2242	0.0000**
Y x M	6	1.4091	17.1663	0.0000**
Y x S	12	0.2724	3.3180	0.0006**
M x S	2	0.0719	0.8760	0.4202
Y x T	6	0.6385	7.7791	0.0000**
M x T	1	0.3703	4.5118	0.0366
S x T	2	0.3199	3.8976	0.0241
Y x M x S	12	0.1867	2.2742	0.0149
Y x M x T	6	1.4243	17.3522	0.0000**
Y x S x T	12	0.5396	6.5736	0.0000**
M x S x T	2	0.4561	5.5563	0.0054*
Y x M x S x T	12	0.5822	7.0928	0.0000**
Within cell error	84	0.0821		

** Highly significant (P <0.001).
* Significant (P <0.01).

This significance appeared to be caused by the pattern of catch among years at Warren Dunes (station F) differing from that observed at Cook stations (A and B). During 1974 and again in 1979, mean catches at Warren Dunes greatly exceeded those at both Cook stations (Figs. 28 and 29). Because this was observed during both a preoperational year and an operational year, it is probably not a plant effect, but simply a reflection of the clumped distribution of smelt in these areas.

Summary of Operational Effects--

Analyses of the seine, trawl, and gill net data have not revealed any

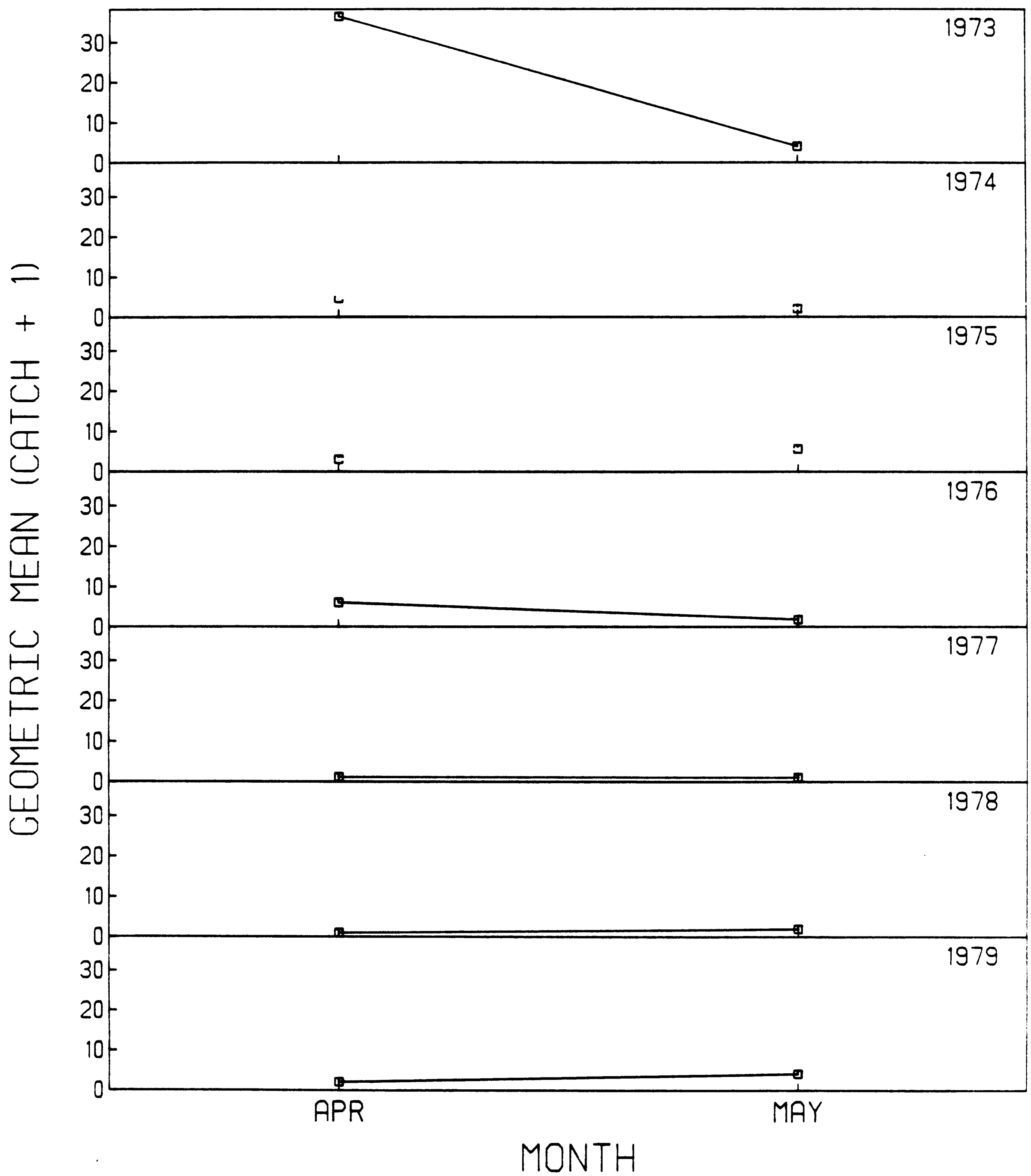


Fig. 27. Monthly geometric mean number of rainbow smelt caught by standard series seining in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

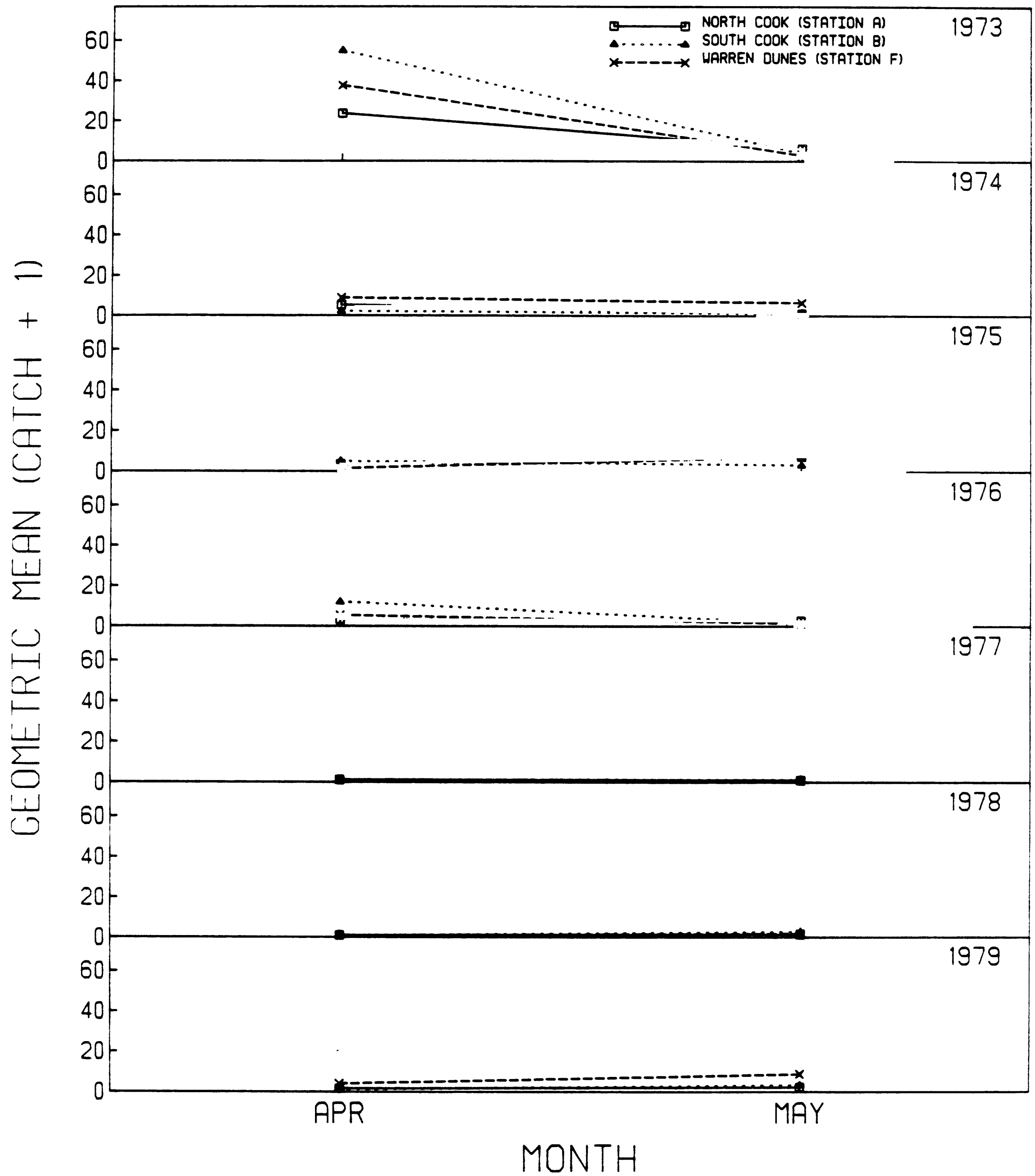


Fig. 28. Monthly geometric mean number of rainbow smelt caught by standard series seining in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975–1979 were operational years.

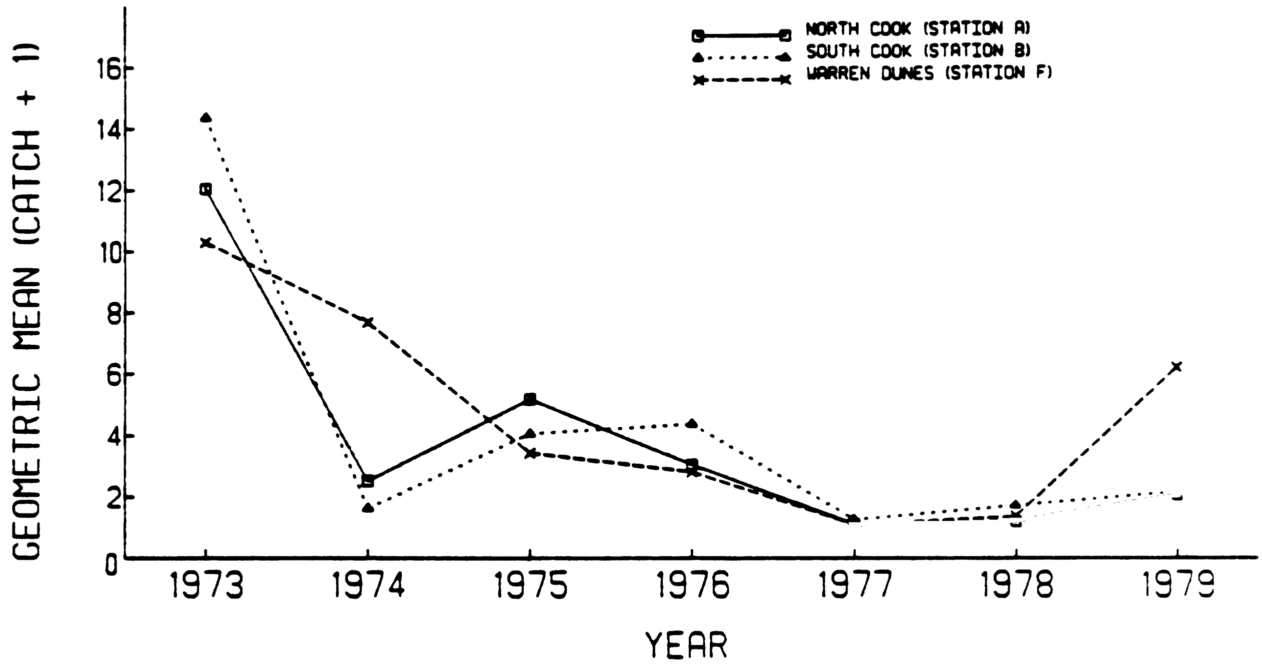


Fig. 29. Yearly geometric mean number of rainbow smelt caught by standard series seining in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

changes in the smelt population at the Cook Plant vicinity attributable to plant operation. All significant differences in catch appeared to be the result of natural population fluctuations, coincidence of the sampling schedule with upwellings and spawning, or a long-term preference by rainbow smelt for the Warren Dunes area over Cook Plant areas. Results of analysis of the gill net data suggest possible plant effects due to the start of Unit 2 operation. However, analysis of trawl and seine data does not support this conclusion. Furthermore, judging from the relative power of the statistical tests employed in these analyses, more emphasis in drawing conclusions about plant-related impacts should be placed on seine and trawl data than gill net data. Weighing all these considerations supports the general conclusion that there have not been any significant plant-related impacts on the rainbow smelt population.

Distribution and Growth by Age-Group--

Analysis of length-frequency histograms (Fig. 30) allowed determination of the age distribution for young-of-the-year (YOY) and yearling smelt. This method readily distinguished YOY individuals. However, there was overlap of lengths between yearlings and age-2 fish. Age determination for individuals beyond age 2 was not possible due to widely overlapping length distributions of older smelt.

Young-of-the-Year--Total catches among age-groups fluctuated considerably from 1973 to 1979 (Fig. 31). Catch of YOY showed the most dramatic fluctuations. The YOY catch was generally a good predictor of age-1 smelt abundance the following year (Fig. 31). Hence, standard series fishing appeared to provide a reliable index of the year-to-year fluctuations in abundance of these age-size classes of smelt in southeastern Lake Michigan. In 1973, 1974, and 1978, strong smelt year classes were produced. The 1975 and 1976 year classes were notably weak. Strong year classes were produced in both preoperational sampling years and one operational year. The weak year classes were only observed during operational years. However, any plant effect on year-class formation was not readily distinguishable from other factors limiting abundance.

Growth of YOY smelt fluctuated through the season and among years from 1973 to 1979. YOY were first recruited into standard series fishing gear during July in 1973, 1976, 1977, and 1979 (Fig. 32). In these years mean lengths of YOY during July ranged from 28 to 35 mm. YOY were first recruited in August during 1974, 1975, and 1978; they ranged in mean length from 33 to 41 mm. Growth rates of these fish were rapid through October every year (0.28 mm/day). Mean lengths of YOY in July and August were not good

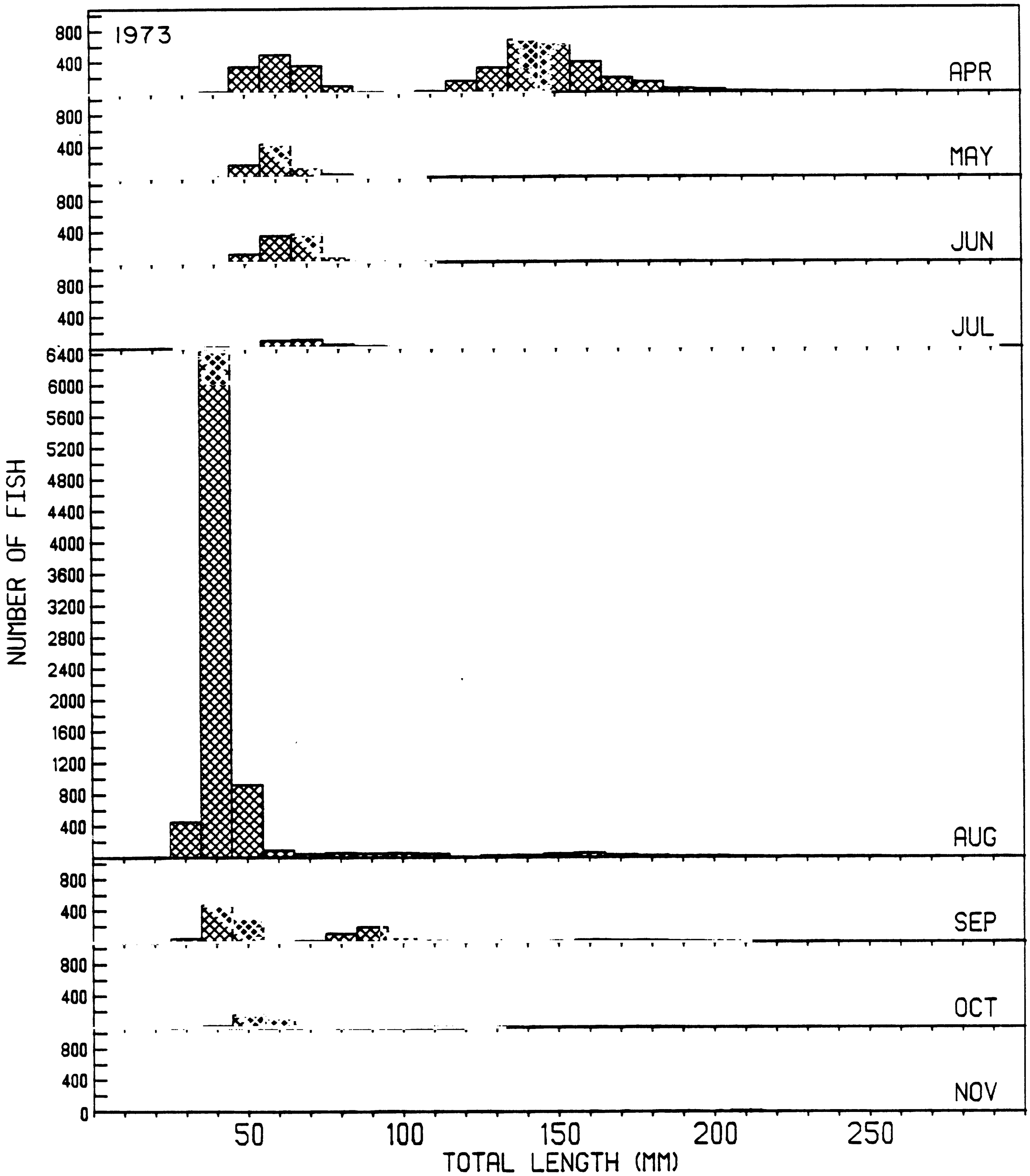


Fig. 30. Monthly length-frequency histograms of rainbow smelt caught during 1973-1979 by standard series trawling, gillnetting, and seining in Cook Plant study areas, southeastern Lake Michigan.

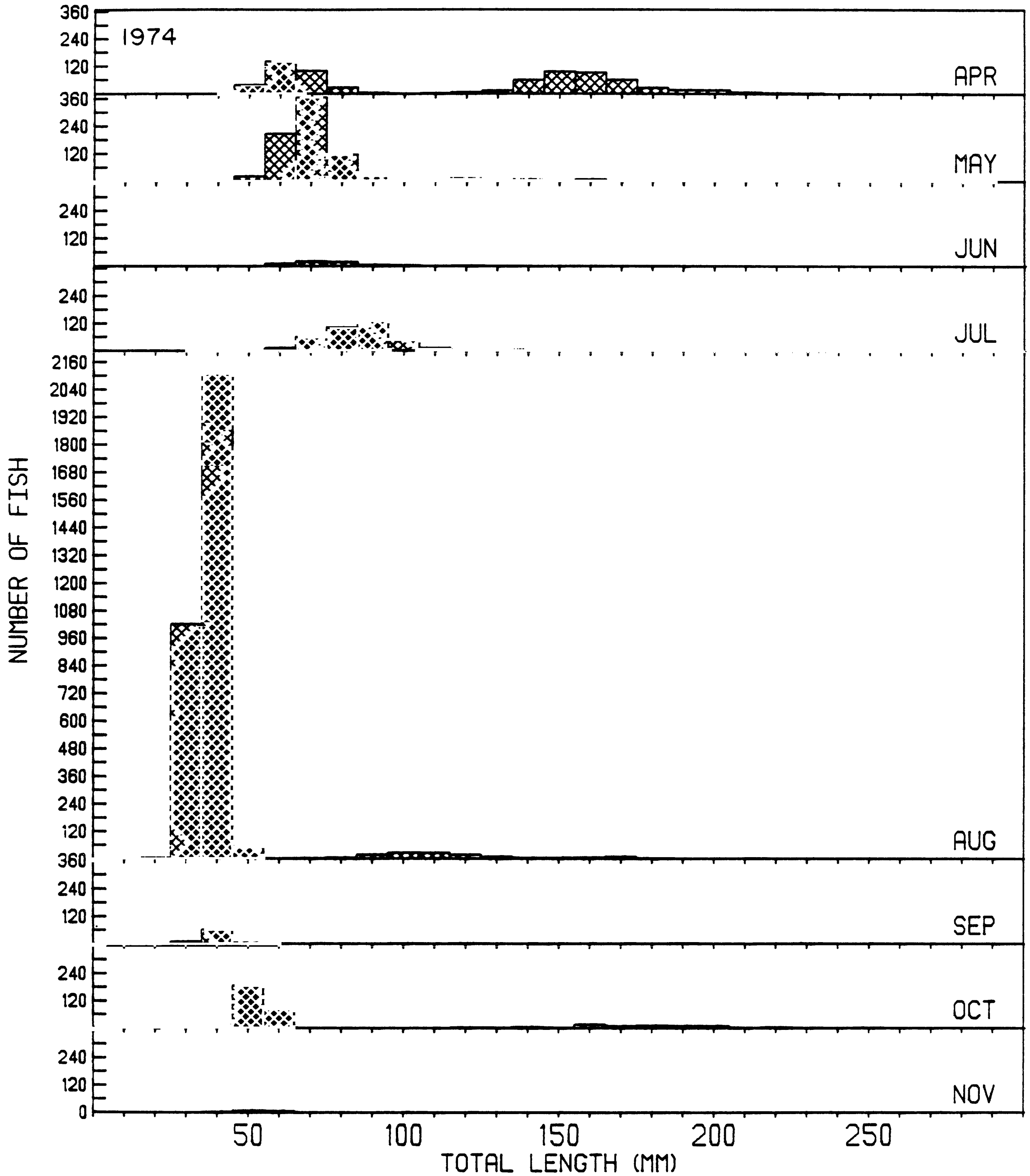
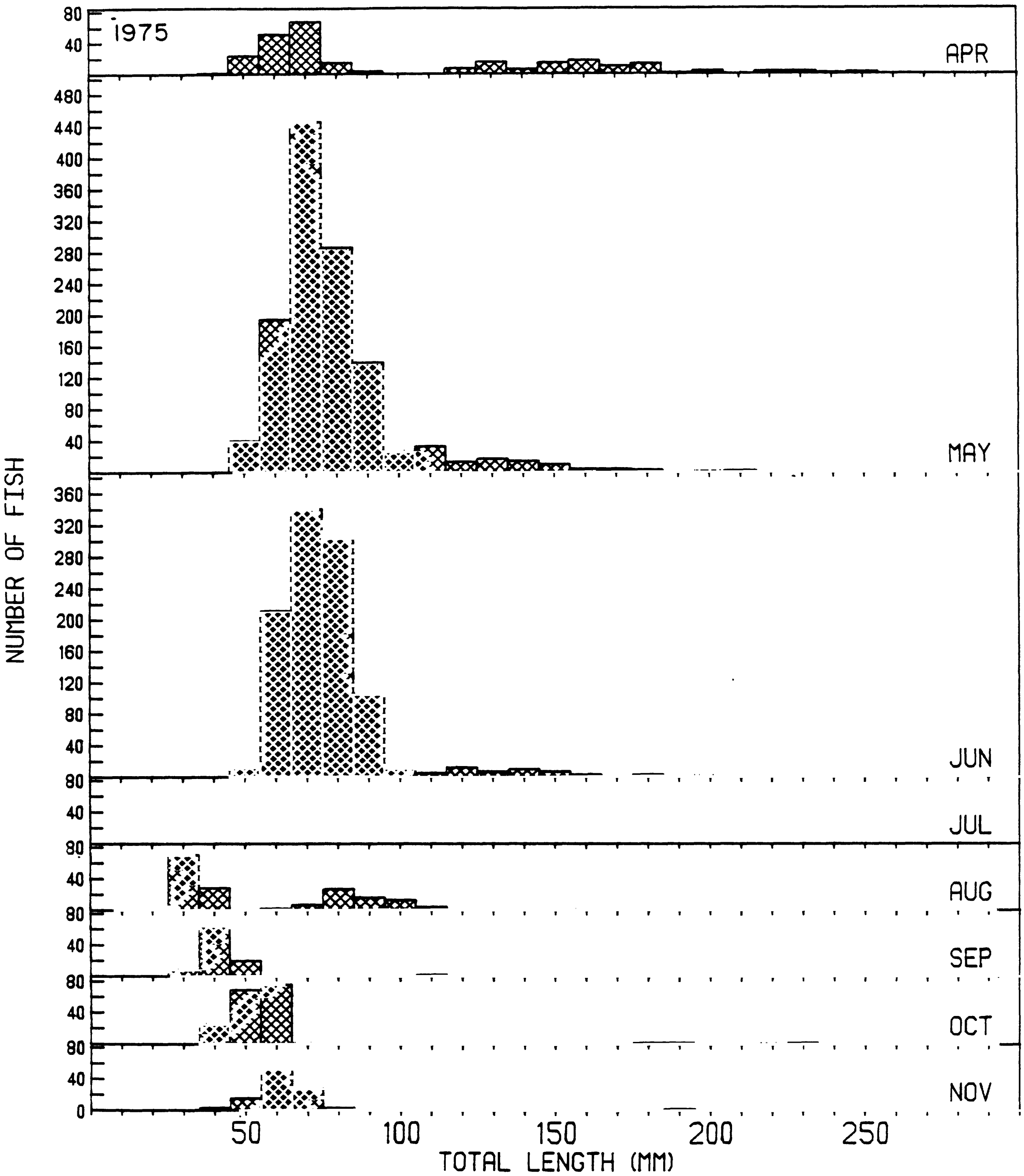


Fig. 30. Continued.



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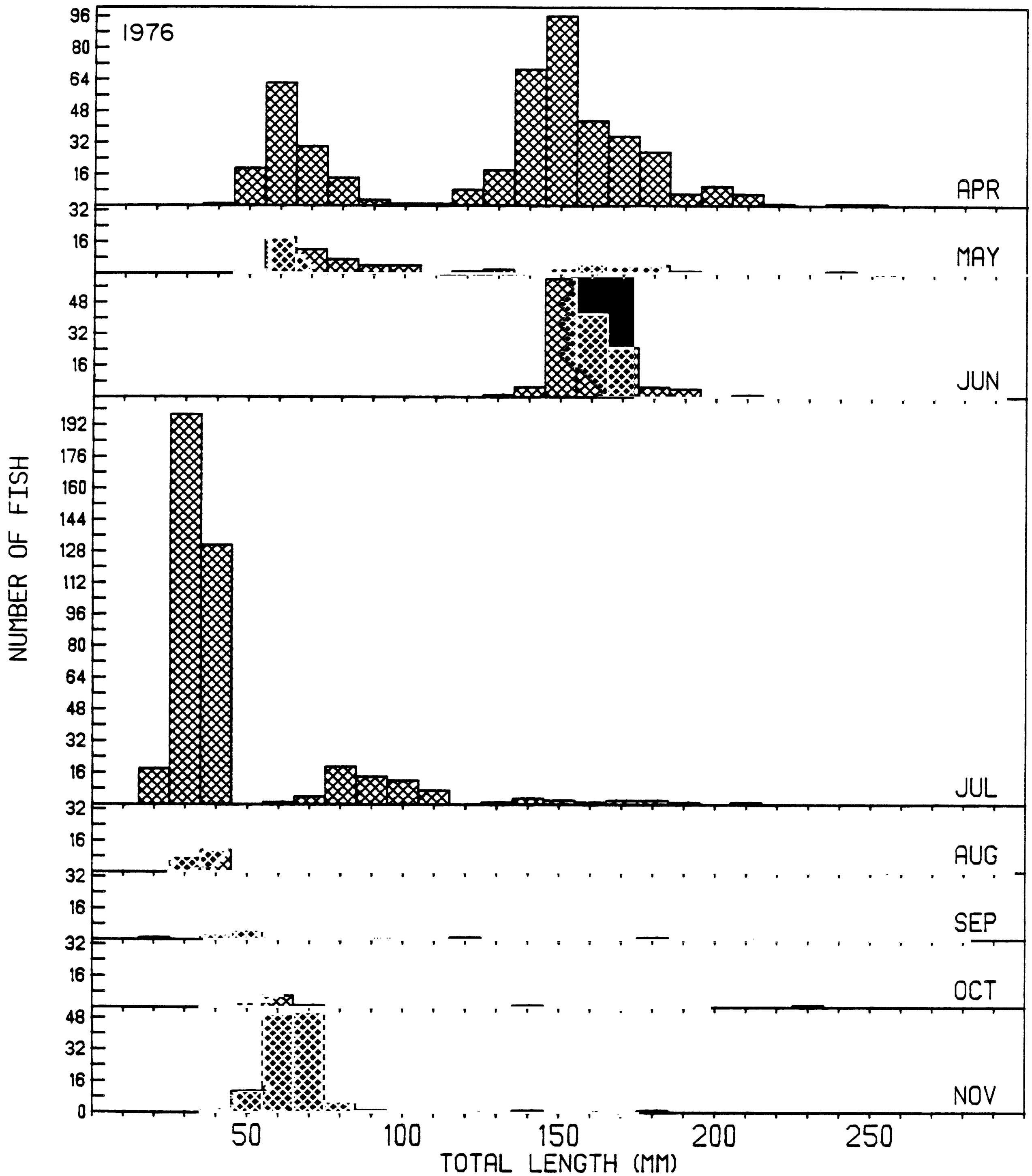

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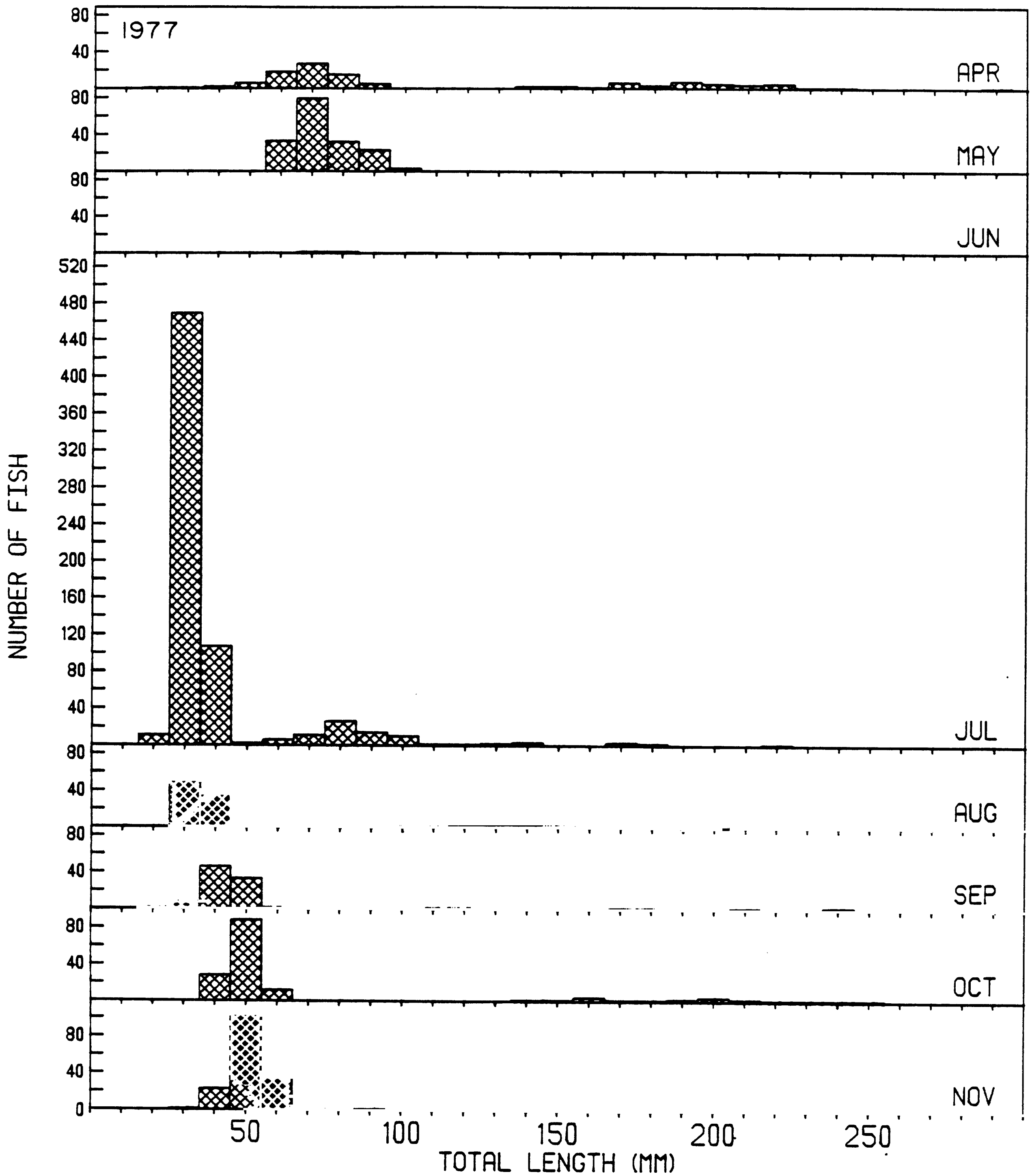

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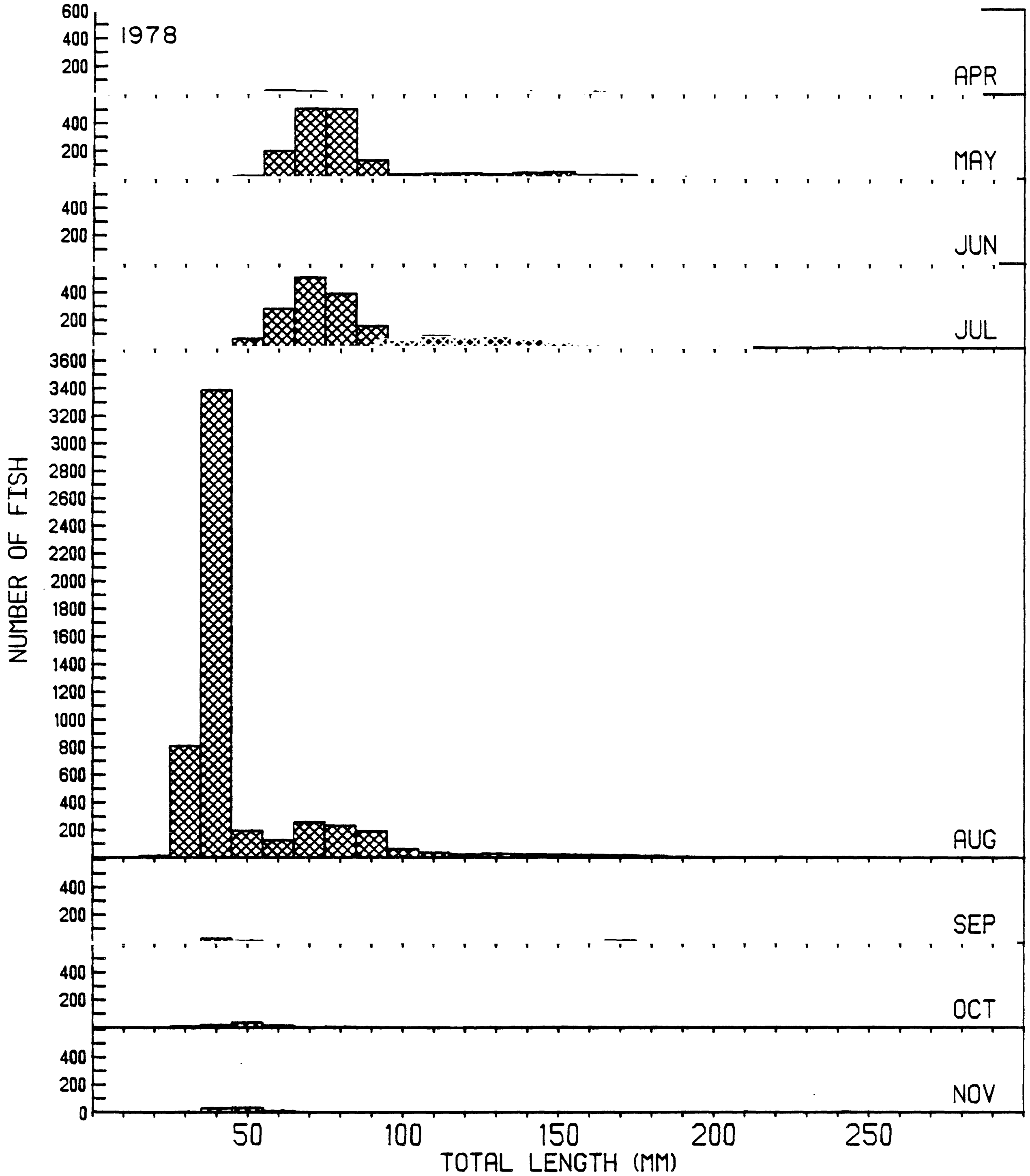

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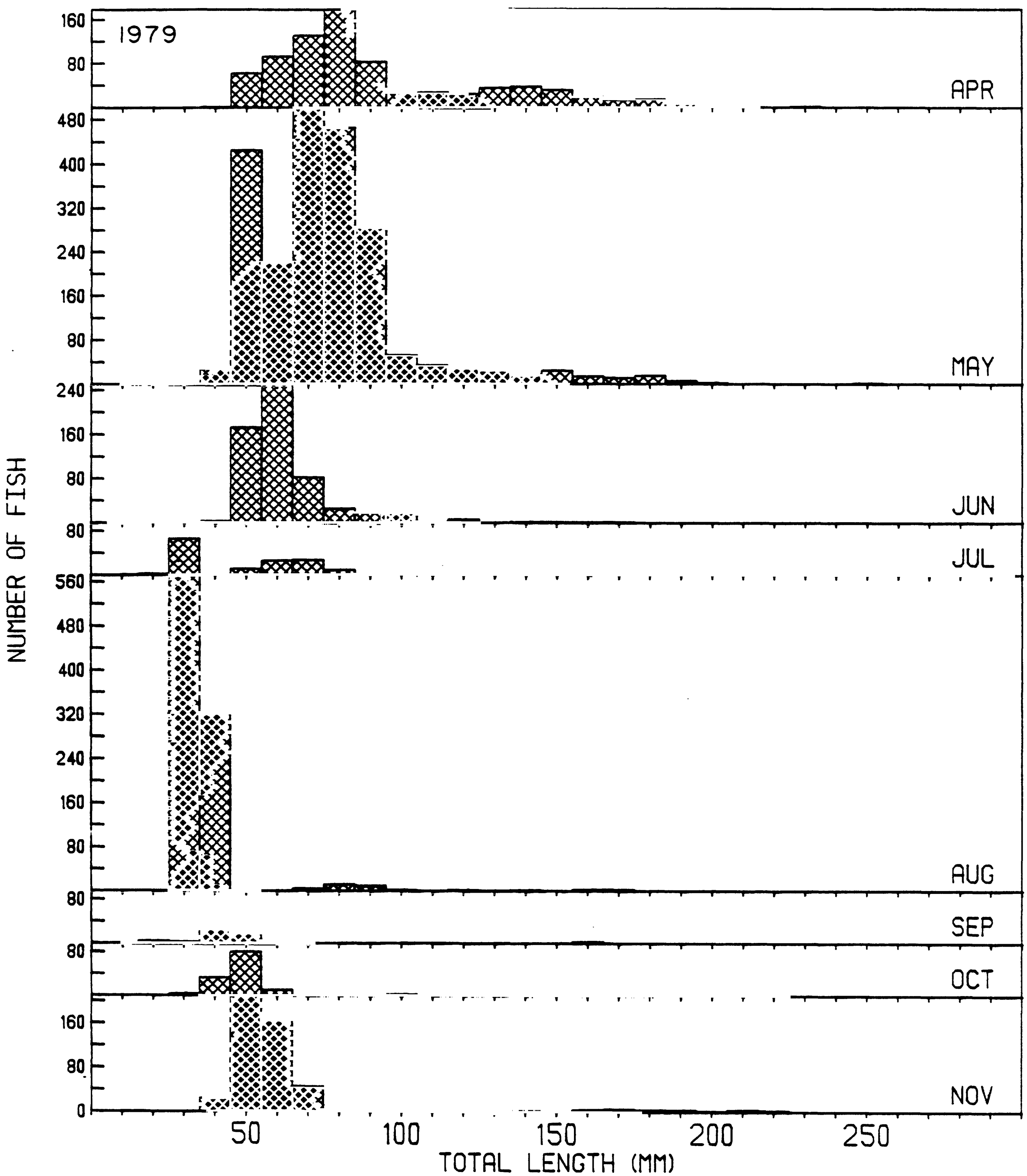

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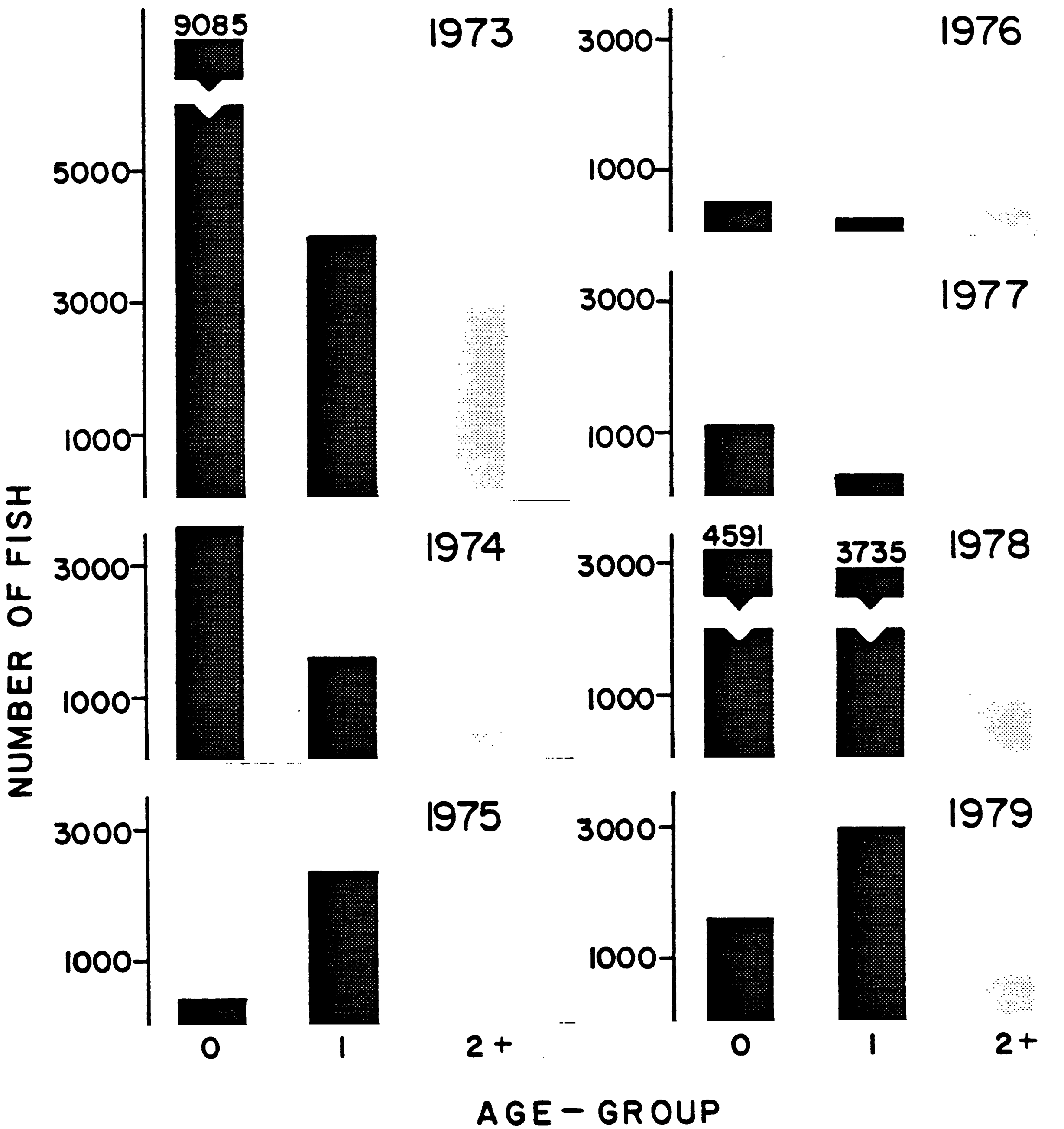


Fig. 31. Age distribution of rainbow smelt caught by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan.

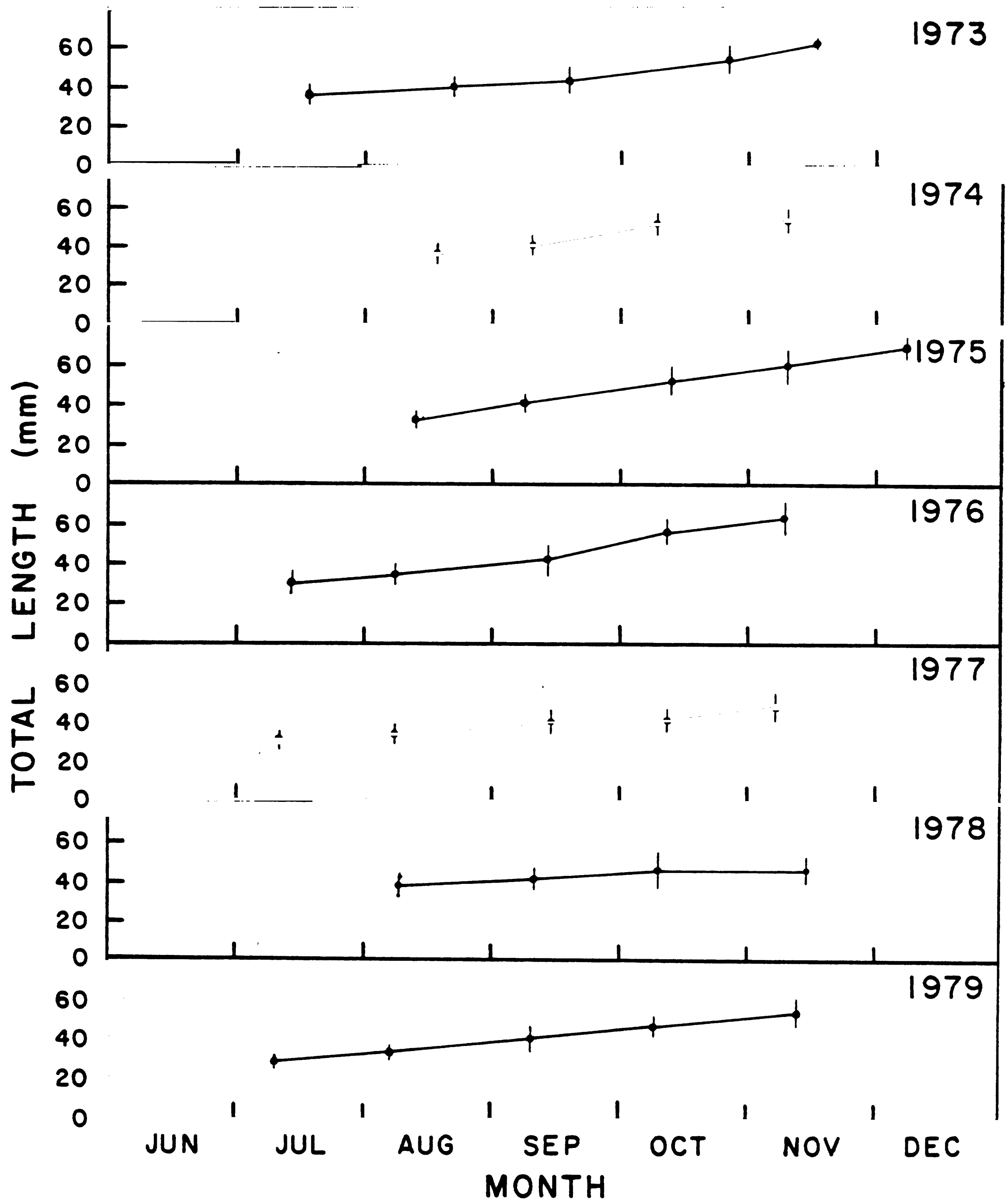


Fig. 32. Mean total length (± one standard deviation) of young-of-the-year rainbow smelt caught during 1973-1979 by standard series trawling, gillnetting, and seining in Cook Plant study areas, southeastern Lake Michigan.

predictors of lengths attained by fall. Years when YOY were recruited into standard series gear at relatively large sizes did not necessarily indicate these cohorts ultimately attained greater lengths by the fall or the following spring than other year classes did (Table 26). This is contrary to McKenzie's (1958) findings that longer growing seasons for YOY smelt in the Miramichi River resulted in fish from these year classes attaining greater lengths. Greater sizes persisted as smelt grew older. This relationship was not observed in our study area. Therefore, in southeastern Lake Michigan, factors other than length of growing season must result in the disparate growth among years for YOY smelt.

YOY catches were consistently largest in August and September, which allowed more detailed analysis of growth rates during these months. Calculation of relative growth (Everhart et al. 1975) for this period revealed considerable differences in growth among years. Values for relative growth ranged from a high of 0.25 in 1975 and 1977 to a low of 0.06 in 1978. These 1-month relative growth rates were not related to length attained the following year. However, there was a strong negative correlation ($r = -0.85$) between August-September relative growth and total standard series catch of YOY smelt for the year. This relationship suggests that density-dependent factors, such as intraspecific competition for food, are affecting YOY growth rates. Other density-independent variables, including seasonal water temperatures, upwellings, and severe weather may also have affected growth.

Yearlings--Yearling growth also fluctuated through the season and from year to year (Table 26). Yearlings first caught in April 1973-1979 ranged from 63 to 72 mm mean TL (Fig. 33). Growth was slow (0.10 mm/day) from April to June, then more rapid (0.39 mm/day) through August. As opposed to YOY,

Table 26. Mean length in mm ±SD of rainbow smelt young-of-the-year and yearlings caught by standard series netting in Cook Plant study areas, southeastern Lake Michigan, 1973-1979. Sample size is given in parentheses.

	Year class							
Month	1972	1973	1974	1975	1976	1977	1978	1979
				Young-of-the-year				
Jul		36 ±5 (10)			31 ±5 (112)	32 ±5 (131)		28 ±3 (42)
Aug		40 ±5 (404)	36 ±5 (123)	32 ±4 (36)	35 ±5 (19)	34 ±5 (60)	39 ±5 (221)	34 ±3 (97)
Sep		43 ±6 (154)	41 ±4 (83)	41 ±4 (80)	43 ±9 (9)	42 ±7 (127)	41 ±5 (27)	41 ±6 (89)
Oct		54 ±7 (176)	51 ±6 (118)	52 ±7 (77)	56 ±8 (11)	48 ±5 (130)	47 ±9 (97)	47 ±6 (109)
Nov		62 ±1 (2)	52 ±5 (13)	61 ±8 (111)	64 ±8 (100)	50 ±6 (156)	46 ±6 (70)	55 ±8 (264)
Dec				70 ±7 (14)				
				Yearlings				
Apr	64 ±11 (323)	64 ±9 (245)	64 ±10 (144)	63 ±9 (138)	68 ±13 (104)	62 ±10 (46)	69 ±13 (548)	
May	62 ±10 (292)	70 ±10 (282)	73 ±12 (347)	70 ±13 (52)	72 ±10 (163)	71 ±11 (356)	67 ±14 (635)	
Jun	65 ±11 (233)	73 ±10 (58)	74 ±13 (302)		70 ±7 (2)	60 ±14 (29)	64 ±13 (332)	
Jul	74 ±12 (111)	82 ±14 (102)		89 ±12 (63)	84 ±15 (59)	74 ±13 (816)	67 ±14 (75)	
Aug	87 ±14 (136)	103 ±12 (64)	87 ±12 (59)			79 ±15 (465)	85 ±15 (28)	
Sep	96 ±20 (150)	110 ±8 (2)	106 ±0 (2)	120 (1)	114 ±11 (2)	111 (1)		
Oct	122 ±22 (6)	124 ±9 (3)		142 (1)	139 (1)	88 ±17 (10)	126 ±21 (8)	
Nov				137 (1)	87 (1)		141 (1)	

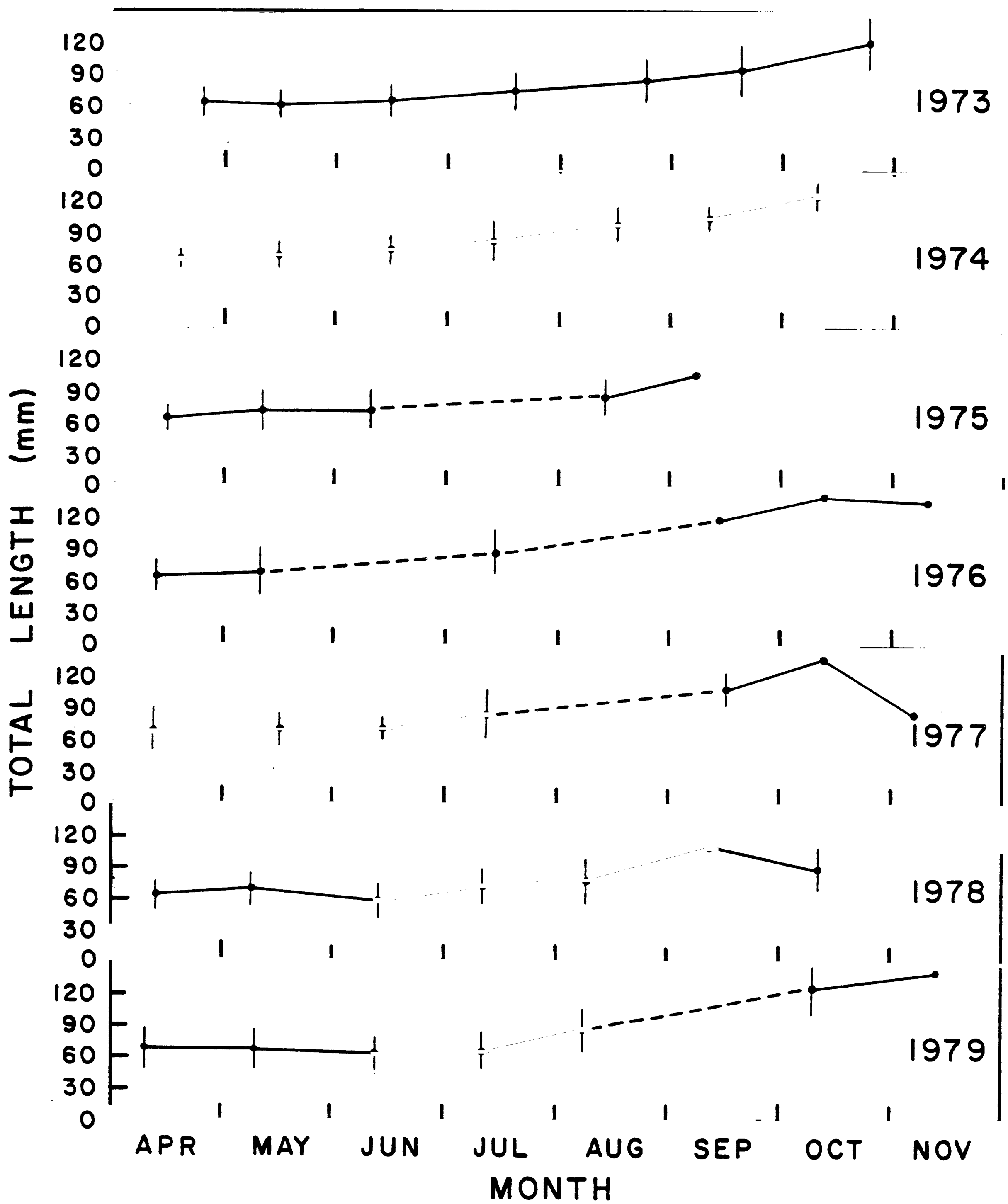


Fig. 33. Mean total length (± one standard deviation) of yearling rainbow smelt caught during 1973-1979 by standard series trawling, gillnetting, and seining in Cook Plant study areas, southeastern Lake Michigan.

yearling lengths in April were fairly good predictors of mid-summer lengths. Only in 1975 were small yearlings caught in April and large yearlings in July. In addition, anomalous decreases in mean lengths occurred from April to May in 1973 and 1979. These decreases may have resulted from difficulty in distinguishing age-1 fish from older individuals because of broadly overlapping length frequencies. An influx of adults for spawning during April may have increased length overlap between these age-groups and given an apparent increase to the mean length of supposed age-1 fish. Yearling catches usually declined after August because of retreat of fish to deeper waters.

Adults--Smelt age 2 and greater were infrequently caught because they were susceptible to standard series fishing gear only during upwellings and the spring spawning season. Adults usually resided in areas farther offshore than sampled by our gear. Hence, it was more difficult to adequately index the abundance of these individuals than YOY or yearlings. However, large catches of age-2 and older fish usually followed years of large yearling catches (Fig. 33), indicating that a large portion of these fish probably consisted of age-2 individuals each year. Modal length of the April-caught age-2+ size group ranged from 140 to 180 mm from 1973 to 1979 (Fig. 30). Since age-1 individuals attained lengths of 122 to 142 mm by fall (Fig. 30), most smelt that were the modal length in the age-2+ group were undoubtedly age 2. Smelt were also apparently becoming mature by their second year because 90% of all females were mature at 135 mm and 90% of the males at 132 mm. Length at maturity did not appear to vary before or after plant operation.

These growth and maturity data failed to show any plant effects on smelt in the study areas. Growth fluctuated for both YOY and yearlings from 1973 to 1979, but no long-term trends were evident. During plant operational years

overall growth rates remained comparable to growth rates during preoperational years. Growth of adults was more difficult to index. However, no obvious change in the length distribution of smelt was found that could be attributed to factors other than variable year-class strength.

Temperature-catch Relationships--

The distribution of smelt with regard to temperature has been described by several investigators. In southeastern Lake Michigan, Wells (1968) reported a preferred temperature range for smelt from 6 to 14°C. Jude et al. (1979) found that YOY were caught in warmer waters (12-18°C) than yearlings (6-12°C). Adults showed the narrowest range of preferred temperatures from 6 to 8°C. These findings agree well with the preferred temperature (6.1°C) for adult smelt reported for Lake Erie (Ferguson 1965). Ferguson (1965), however, noted that diel changes in the vertical distribution of smelt caused them to occupy a wide range of temperatures over 24 hours. MacCallum and Regier (1970) also pointed out that the distribution of smelt is affected by many factors other than temperature and based on the results of their study, smelt appear to be eurythermal.

In this study, smelt were caught primarily in temperatures from 6.0 to 15.9°C (Fig. 34). This rather wide range of temperatures can be accounted for by the differing thermal preferences of YOY, yearlings, and adults. YOY smelt were most often caught in waters from 15 to 17°C. Yearling smelt predominated in waters from 10 to 13°C and adults were generally caught in waters 10°C or less (Fig. 35). Hence, these findings agree well with previous descriptions of smelt temperature preferences. Adult smelt are known to be cannibalistic on younger age-groups and this segregation of age-groups by temperature may, to some degree, reduce cannibalism by adults.

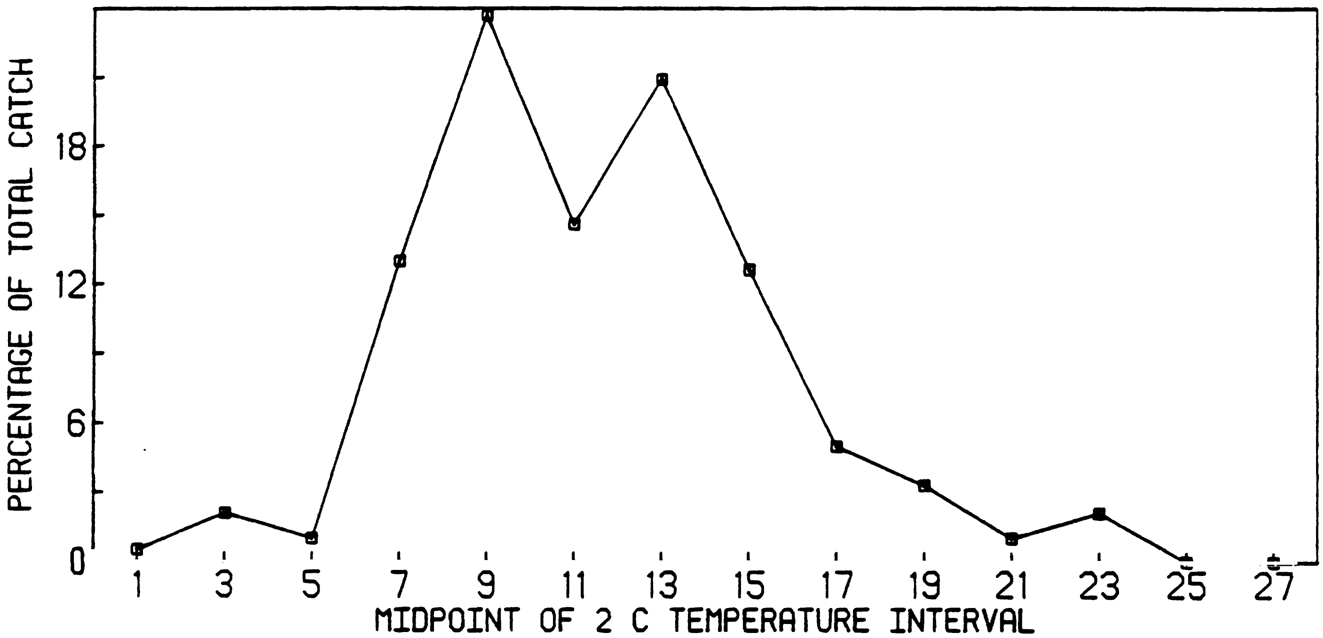


Fig. 34. Percentage of the combined total standard series catch of rainbow smelt collected during 1973-1979 from various temperatures in Cook Plant study areas, southeastern Lake Michigan.

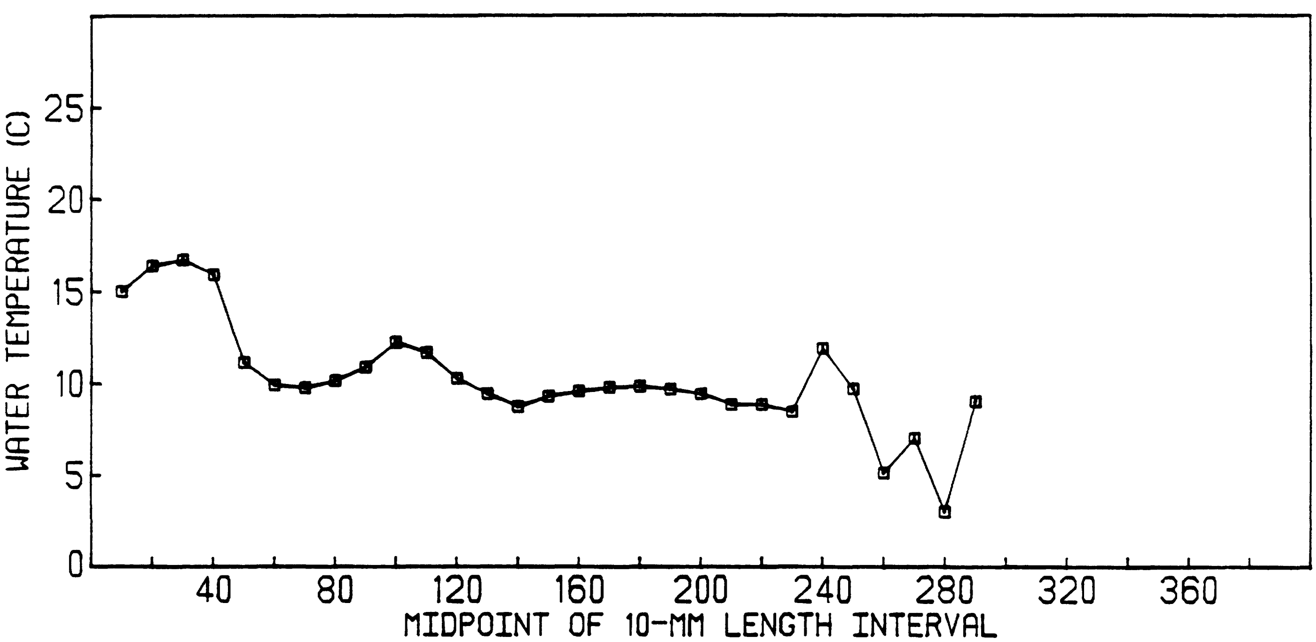


Fig. 35. Mean temperature at which various sizes of rainbow smelt were caught during 1973-1979 by standard series trawling, gillnetting, and seining in Cook Plant study areas, southeastern Lake Michigan.

Spottail Shiner

Introduction—

Spottail shiners are distributed throughout most of North America (Scott and Crossman 1973) and are usually limited to the shallower areas of lakes and rivers (Wells 1968). This species is found in all of the Great Lakes and is abundant in southeastern Lake Michigan (Wells and House 1974; Jude et al. 1975, 1979). Spottail shiners can be important forage for sport fish (Smith and Kramer 1964, Wells and House 1974, Anderson and Brazo 1978); however, few were eaten by the salmonids and yellow perch we examined. Spottail shiners are frequently used for bait fish and occasionally in fish culture systems where live forage is necessary. Details of spottail life history in midwestern lakes and rivers can be found in McCann (1959), Griswold (1963), Smith and Kramer (1964), Peer (1966), Wells (1968), and Wells and House (1974).

The relative abundance and distribution of spottail shiners in our study areas followed predictable seasonal patterns. During winter, catches were minimal. Wells (1968) found that Lake Michigan spottails overwinter in moderately deep water (9 to 37 m). Impingement samples at the Cook Plant show that spottails are common at the plant's intakes (7 m) in winter (Thurber and Jude 1984). Shoreward migration begins in March. During May, spottails were most abundant at 6-9-m depths fished by our gill nets and trawls. Seine catches peaked from May to July as spottails continue moving toward the shore to spawn. Spawning, as judged from gonad condition, began in June and continued through August as is typical in southeastern Lake Michigan (Wells 1968). Seine catches of adults decreased in August, while trawls and gill net catches increased, suggesting a post-spawning dispersal to deeper waters.

Young-of-the-year (YOY) spottails were recruited to our gear in August and in some years this resulted in major increases in seine and trawl catches through October. Spottail abundance declined in the fall via mortality and a continuing movement to deeper water. Impingement of spottail shiners also follows this pattern. Increased numbers of spottails were impinged in April as they move through the 7-m (depth of plant intakes) depth zone prior to spawning. Impingement was minimal from May to June because adults are usually nearshore during spawning. Numbers of adults impinged increased in July as they moved to deeper water. YOY spottail impingement increased in September as fish disperse from the beach zone.

Spottail shiner was the second-most abundant species collected in all survey years (1973-1979). They comprised from 9% (14,115 - 1975) to 40% (30,399 - 1978) of standard series catches. Standard series seines, trawls, and gill nets, respectively, accounted for 70%, 21%, and 9% of the total spottail catch. Spottails were collected in almost every month by either standard series gear or impingement. Spottail shiner impingement fluctuated from 5,220 (1977) to 59,605 (1979) and accounted from 4.4% (1975) to 28% (1978) of total annual impingement. Spottails were one of the four most often impinged species at the plant. Larvae were collected annually in field and entrainment sampling from June to August in most years and as late as October (1976). The recruitment of strong year classes produced in 1977 and 1979 to our various gear as YOY, yearlings, and adults had considerable impact on our statistical interpretation of catch trends for this species.

Trawl Data--

Years--Trawl ANOVA applied to 1973-1979 data showed that Year, Month, Depth and Time main effects were highly significant but Area was not

(Table 27). Significant Year effects were the result of substantial annual population fluctuations and the production of large year classes in 1977 and 1979. Large catches in 1973, 1976, 1978, and 1979 and small catches in 1974 and 1975 contributed to the significance of these effects. These fluctuations are probably not plant induced. Scheffe's test between means for Year effects indicated no significant differences between catches of preoperational years and operational years. Results of tests of significance between trawl and gill net catches corresponded to the variability of year-class strength and suggest that significant Year interactions would occur in those years when either extremely large or small year classes entered the population. For example, when 1979 was included in any test of means, comparisons were always significant due to catch increases resulting from the large 1979 year class that was recruited to trawl catches in the fall. Significant Year and Month main effects and associated first- and second-order interactions (Table 27) were most likely due to seasonal behavioral patterns of the species including large-scale movements of spottails to inshore areas for spawning, their subsequent exit in late summer, and recruitment of YOY to our gear in the fall. These influences were especially notable when large year classes entered the population. For example, a strong 1977 year class was recruited to trawl catches in September 1977 causing a major catch increase. This same year class persisted in our catch in June 1978 and October 1978, again escalating catches. The 1977 year class probably contributed substantially to the 1979 spawning population (June) which resulted in the production of a large 1979 year class (Fig. 36).

Areas--Area main effects were not significant. The nonsignificance of the Year x Area interaction suggests that most catch increases or declines

Table 27. Analysis of variance summary for log(catch + 1) of spottail shiners. Fish were trawled from April to October, 1973-1979 in Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df#	Adjusted mean square##	F-statistic	Attained significance
Year	6	2.4113	46.3651	0.0000**
Month	6	9.1380	175.7076	0.0000**
Area	1	0.0355	0.6819	0.4094
Depth	1	8.1633	156.9667	0.0000**
Time	1	87.1967	1,676.6445	0.0000**
Y x M	36	3.1161	59.9176	0.0000**
Y x A	6	0.1258	2.4194	0.0262
M x A	6	0.8105	15.5853	0.0000**
Y x D	6	0.3899	7.4967	0.0000**
M x D	6	0.6492	12.4822	0.0000**
A x D	1	0.1259	2.4207	0.1205
Y x T	6	1.1873	22.8289	0.0000**
M x T	6	3.6983	71.1120	0.0000**
A x T	1	2.0953	40.2893	0.0000**
D x T	1	5.0876	97.8251	0.0000**
Y x M x A	36	0.3747	7.2046	0.0000**
Y x M x D	36	0.3590	6.9024	0.0000**
Y x A x D	6	0.1480	2.8458	0.0101
M x A x D	6	0.1261	2.4142	0.0159
Y x M x T	36	1.3747	26.4324	0.0000**
Y x A x T	6	0.4646	8.9339	0.0000**
M x A x T	6	0.6577	12.6466	0.0000**
Y x D x T	6	0.4759	9.1505	0.0000**
M x D x T	6	0.4074	7.8338	0.0000**
A x D x T	1	0.2632	5.0616	0.0250
Y x M x A x D	36	0.1571	3.0217	0.0000**
Y x M x A x T	36	0.3288	6.3227	0.0000**
Y x M x D x T	36	0.3328	6.3996	0.0000**
Y x A x D x T	6	0.2170	4.1729	0.0004**
M x A x D x T	6	0.2780	5.3458	0.0000**
Y x M x A x D x T	36	0.1330	2.5566	0.0000**
Within cell error	390	0.0520		

\# Two degrees of freedom were subtracted from the error term to correct for two missing observations where cell means were substituted.

\## Mean squares were multiplied by harmonic mean cell size/maximum cell size (nh/n = 0.9949) to correct for two missing observations where cell means were substituted.

** Highly significant (P <0.001).

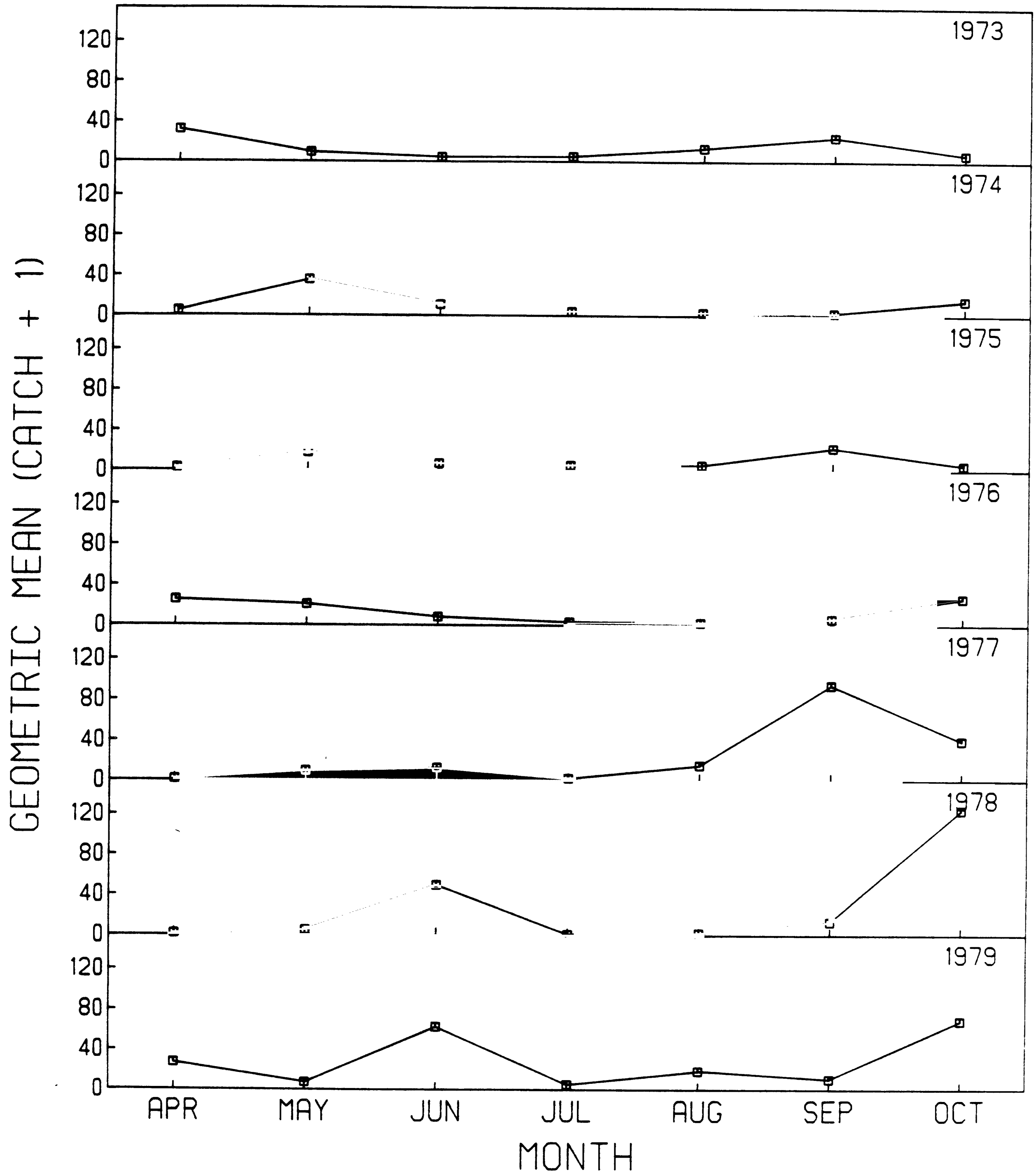


Fig. 36. Monthly geometric mean number of spottail shiners caught by standard series trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

occurred simultaneously at Cook and Warren Dunes stations (Fig. 37). This is additionally supported by lack of significance of Year x Area x Depth, Month x Area x Depth, and Area x Depth x Month interactions. Significant interactions occurred when month entered some interactions (Year x Month, Year x Month x Area). These differences are probably a result of this species' seasonal behavior patterns, variations in catch composition (YOY, yearlings, and adults), and strength of year classes. Additionally, a trend of larger catches at Warren Dunes stations has occurred in some recent years. Large YOY and yearling catches at Warren Dunes in 1977, 1978, and 1979 and increased catches of spawning adults at Cook in May 1974 contributed substantially to causing these interactions to be significant. However, Scheffe's test between mean catches at trawl stations (1975-1979) indicate that no statistically significant differences occurred between years, except for 1979, a probable effect of the large 1979 year class. These findings indicate no impact of plant operation on spottails surveyed by trawling gear. Although catch differences occur in some years among stations, length-frequency analysis indicates no substantial difference between spottail populations at Cook and Warren Dunes.

Scheffe's test of means indicated that catch fluctuations appear to occur simultaneously at most trawl stations with minor variations in some years. Annual station catch variation accounted for the significant Station main effect when station R was included in ANOVA for 1975-1979 (Table 28). A major source contributing to these variations was the large 1979 spottail catch (Fig. 38). Scheffe's test showed no statistically significant catch differences between station R and other Cook Plant trawl stations or among 6-m stations at either Cook or Warren Dunes.

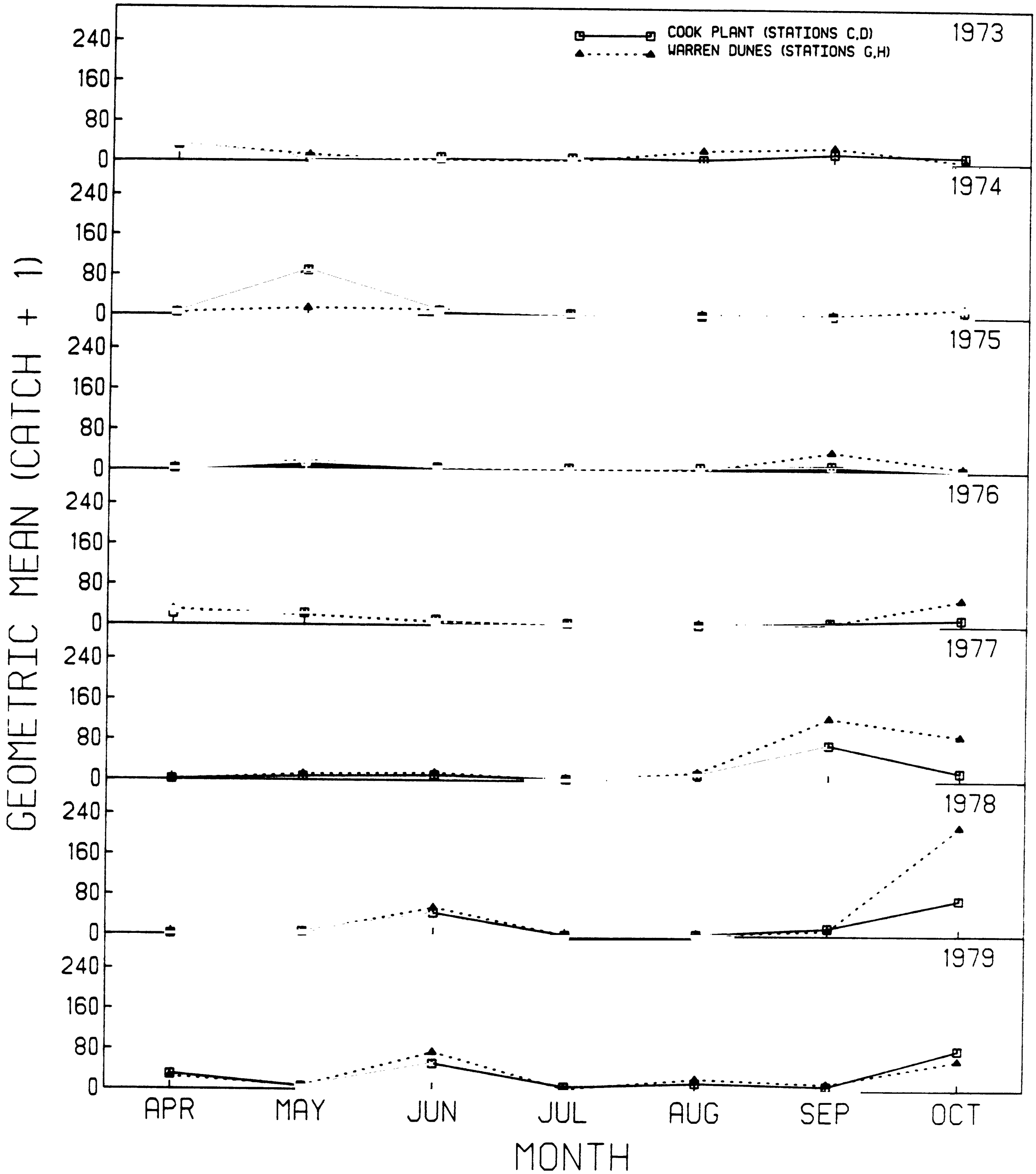


Fig. 37. Monthly geometric mean number of spottail shiners caught by standard series trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

Table 28. Analysis of variance summary for log(catch + 1) of spottail shiners. Fish were trawled from April to October, 1975-1979 in Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df	Mean square	F-statistic	Attained significance
Year	4	4.1566	64.5885	0.0000**
Month	6	12.2990	191.1121	0.0000**
Station	4	1.2007	18.6568	0.0000**
Time	1	117.6062	1,827.4661	0.0000**
Y x M	24	3.8607	59.9907	0.0000**
Y x S	16	0.1959	3.0448	0.0001**
M x S	24	0.4560	7.0860	0.0000**
Y x T	4	0.6688	10.3918	0.0000**
M x T	6	3.3941	52.7399	0.0000**
S x T	4	1.7781	27.6294	0.0000**
Y x M x S	96	0.1792	2.7847	0.0000**
Y x M x T	24	1.5164	23.5625	0.0000**
Y x S x T	16	0.1996	3.1020	0.0001**
M x S x T	24	0.3068	4.7675	0.0000**
Y x M x S x T	96	0.2910	4.5223	0.0000**
Within cell error	350	0.0644		

** Highly significant (P <0.001).

Gill Net Data--

<u>Years</u>--Gill net ANOVA showed significant main effects of Year, a possible result of variable year-class strength (Table 29). Larger gill net catches in 1973, 1974, 1976, and 1979 and smaller catches in 1975, 1977, and 1978 contributed to this variation (Fig 39). Large spawning aggregations from May to June also contributed to causing month interactions to be significant.

<u>Areas</u>--No significant differences in catches have occurred at Cook or Warren Dunes standard series stations. Main Area effects, Year x Area, and Area x Depth interactions were not significant (Table 29). However, the Month x Area interaction was significant. In some years spawning aggregations

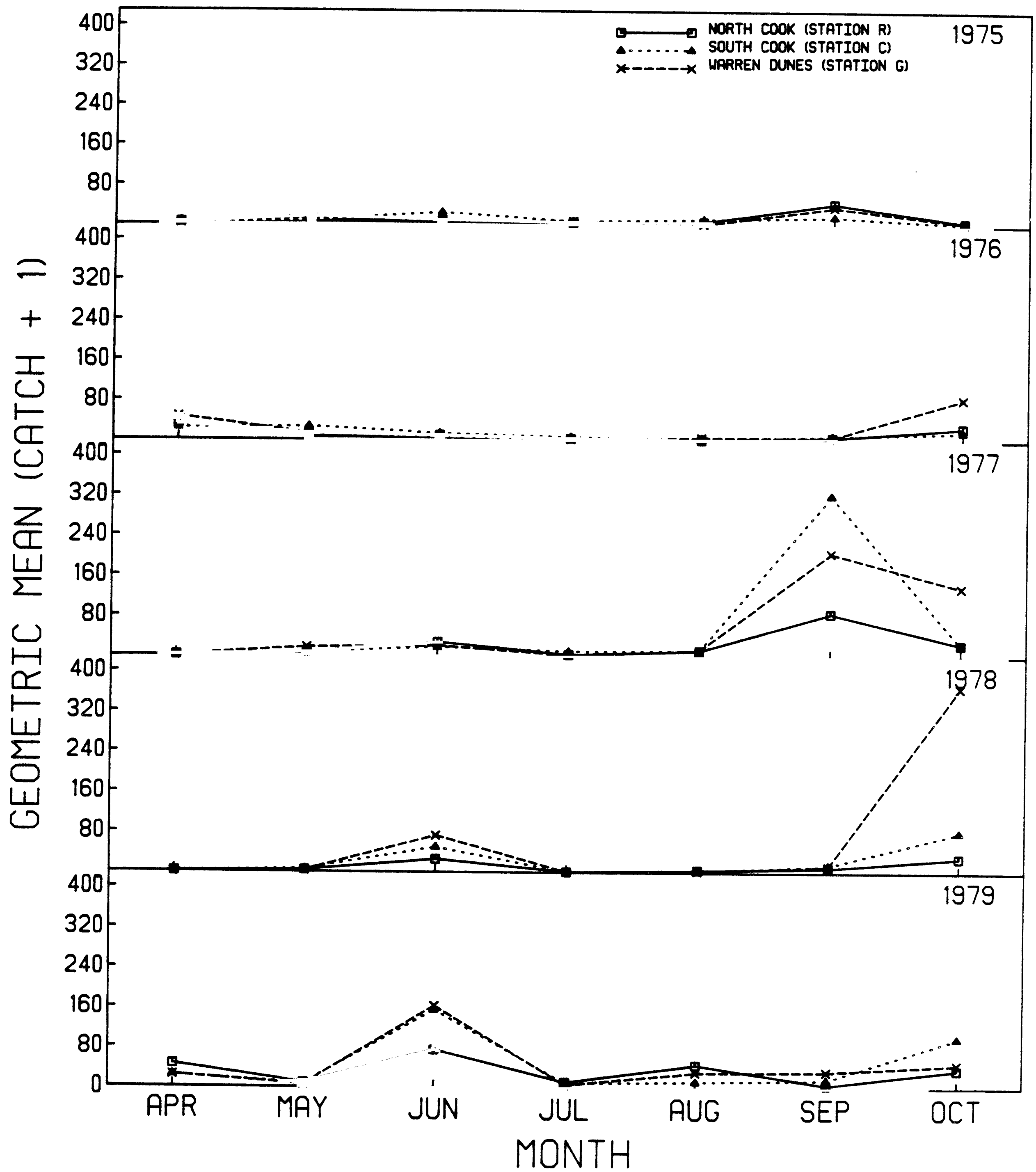


Fig. 38. Monthly geometric mean number of spottail shiners caught during operational years 1975-1979 by standard series and station R trawling in Cook Plant study areas, southeastern Lake Michigan.

Table 29. Analysis of variance summary for $\log_{10}$(catch + 1) of spottail shiners. Fish were gillnetted from April to September, 1973-1979 in Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df	Mean square	F-statistic	Attained significance
Year	6	2.8916	30.1998	0.0000**
Month	5	2.3373	24.4105	0.0000**
Area	1	0.1493	1.5598	0.2214
Depth	1	1.2296	13.5734	0.0090*
Time	1	35.1110	366.6953	0.0000**
Y x M	30	1.3194	13.7792	0.0000**
Y x A	6	0.0805	0.8410	0.5439
M x A	5	0.3731	3.8971	0.0077*
Y x D	6	0.1003	1.0476	0.4150
M x D	5	0.3353	3.5019	0.0130
A x D	1	0.1351	1.4105	0.2443
Y x T	6	0.6163	6.4363	0.0002**
M x T	5	0.6059	6.3276	0.0004**
A x T	1	0.7894	8.2442	0.0074*
D x T	1	4.6684	48.7571	0.0000**
Y x M x A	30	0.4356	4.5495	0.0000**
Y x M x D	30	0.3241	3.3853	0.0006**
Y x A x D	6	0.0284	0.2964	0.9338
M x A x D	5	0.1500	1.5667	0.1996
Y x M x T	30	0.7437	7.7675	0.0000**
Y x A x T	6	0.3725	3.8907	0.0054*
M x A x T	5	0.1444	1.5080	0.2169
Y x D x T	6	0.0615	0.6423	0.6957
M x D x T	5	0.1924	2.0094	0.1059
A x D x T	1	0.0129	0.1344	0.7165
Y x M x A x D	30	0.0740	0.7733	0.7572
Y x M x A x T	30	0.2087	2.1798	0.0183
Y x M x D x T	30	0.1795	1.8746	0.0452
Y x A x D x T	6	0.0923	0.9640	0.4660
M x A x D x T	5	0.1533	1.6008	0.1902
Y x M x A x D x T#	30	0.0957		

** Highly significant (P <0.001).
* Significant (P <0.01).
# The Y x M x A x D x T interaction is assumed to be zero and its mean square is treated as the within cell error mean square.

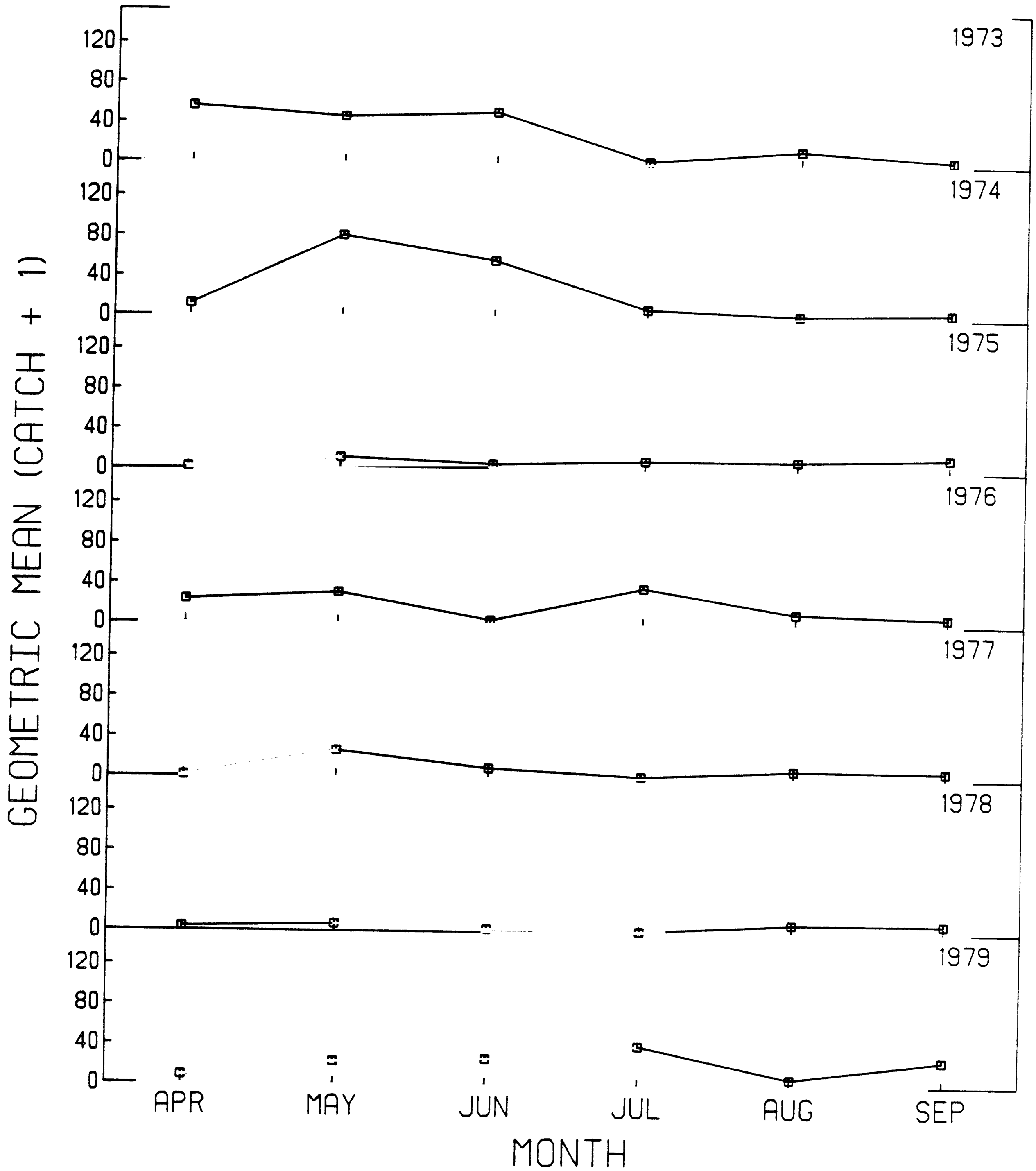


Fig. 39. Monthly geometric mean number of spottail shiners caught by standard series gillnetting in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

were larger at Cook Plant stations and some fall Warren Dunes catches were larger than those at Cook, but no consistent trend could be attributed to Cook Plant operation (Fig. 40).

As with area main effects and interactions, gill net catches at stations R and Q (6 and 9 m, north Cook) occasionally varied from those at other standard series stations (Table 30) (Fig. 41). No consistent pattern emerged that could be attributed to Cook Plant operation.

Seine Data--

Years--Year main effect and the Year x Station interaction were nonsignificant suggesting that plant operation was not influencing beach zone spottail populations (Table 31). Month main effect and Month x Year interactions were significant. The major contributor to these effects was the movement of spottail shiners to the beach for spawning in June and July (Fig. 42).

Areas--Lack of significant station effects during 1973-1979 supports the contention that plant operation had little influence on spottails surveyed by this gear. The significance of the Month x Station interaction can be attributed to spawning aggregations increasing catches in summer months (Fig. 43). Although some variations are indicated, no consistent trend could be identified.

Summary of Operational Effects--

Significant changes in the distribution or abundance of spottail shiners in the study areas were not directly attributable to plant operation. Most significant interactions were associated with complex interrelations of year-class variability, seasonal behavioral patterns, and gear selectivity. Year-class variability and behavioral characteristics of the species appear to overshadow

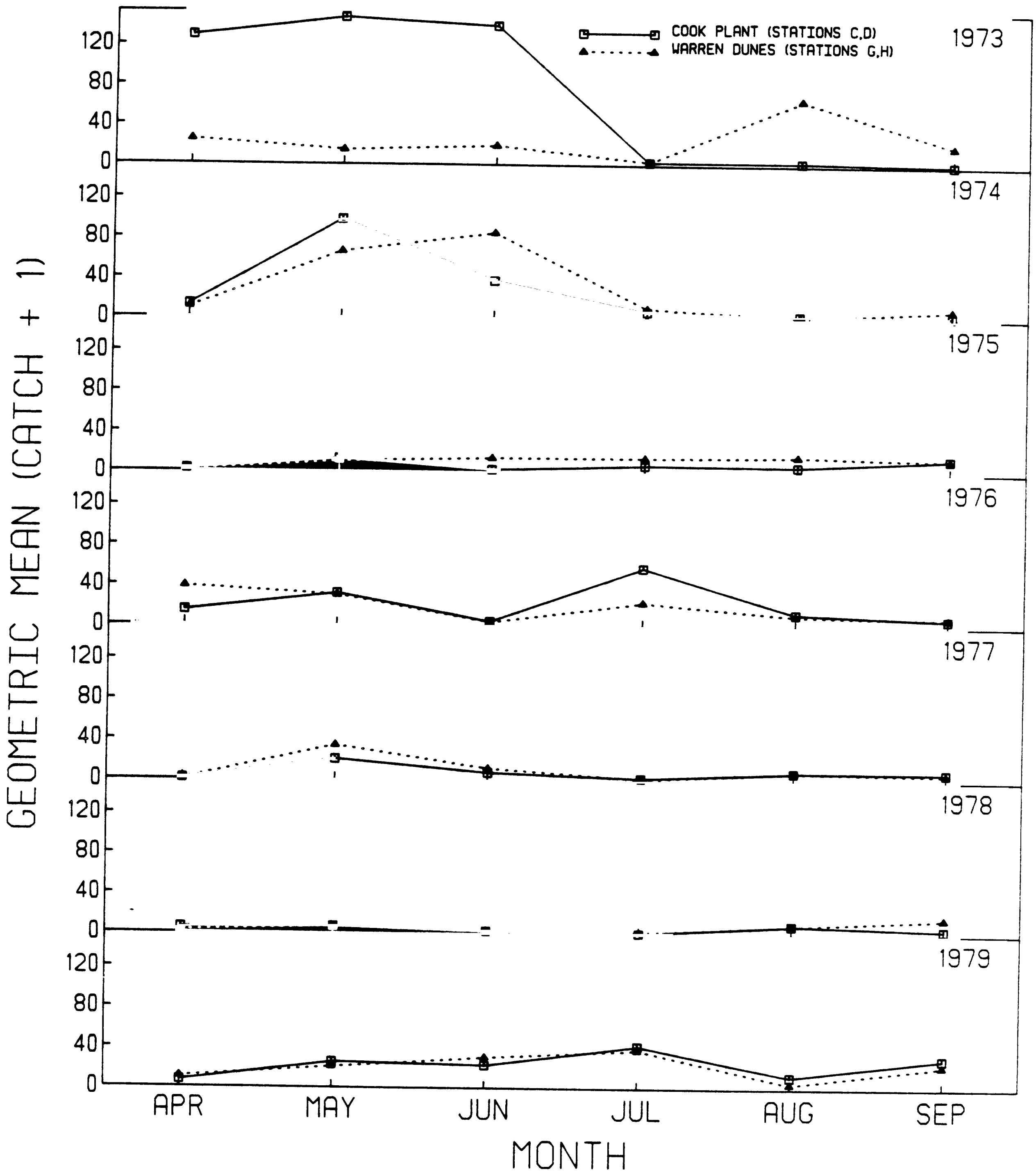


Fig. 40. Monthly geometric mean number of spottail shiners caught by standard series gillnetting in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

Table 30. Analysis of variance summary for log(catch + 1) of spottail shiners. Fish were gillnetted from April to September, 1975-1979 in Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df	Mean square	F-statistic	Attained significance
Year	4	4.8632	43.8863	0.0000**
Month	5	2.3660	21.3512	0.0000**
Area	2	0.2062	1.8606	0.1688
Depth	1	1.7395	15.6977	0.0003**
Time	1	38.4522	347.0005	0.0000**
Y x M	20	1.3928	12.5692	0.0000**
Y x A	8	0.0973	0.8783	0.5428
M x A	10	0.1377	1.2425	0.2950
Y x D	4	0.1299	1.1725	0.3375
M x D	5	0.4983	4.4970	0.0024*
A x D	2	0.1065	0.9612	0.3911
Y x T	4	1.3737	12.3962	0.0000**
M x T	5	0.4241	3.8270	0.0063*
A x T	2	0.3244	2.9275	0.0651
D x T	1	4.2226	38.1058	0.0000**
Y x M x A	40	0.1451	1.3095	0.1988
Y x M x D	20	0.2520	2.2744	0.0133
Y x A x D	8	0.0660	0.5960	0.7753
M x A x D	10	0.1584	1.4298	0.2028
Y x M x T	20	1.2740	11.4966	0.0000**
Y x A x T	8	0.0764	0.6896	0.6982
M x A x T	10	0.2188	1.9745	0.0628
Y x D x T	4	0.0460	0.4153	0.7966
M x D x T	5	0.1587	1.4323	0.2337
A x D x T	2	0.1567	1.4140	0.2551
Y x M x A x D	40	0.1062	0.9582	0.5534
Y x M x A x T	40	0.1616	1.4586	0.1184
Y x M x D x T	20	0.2012	1.8159	0.0536
Y x A x D x T	8	0.0603	0.5439	0.8162
M x A x D x T	10	0.0592	0.5340	0.8556
Y x M x A x D x T#	40	0.1108		

** Highly significant (P <0.001).
* Significant (P <0.01).
# The Y x M x A x D x T interaction is assumed to be zero and its mean square is treated as the within cell error mean square.

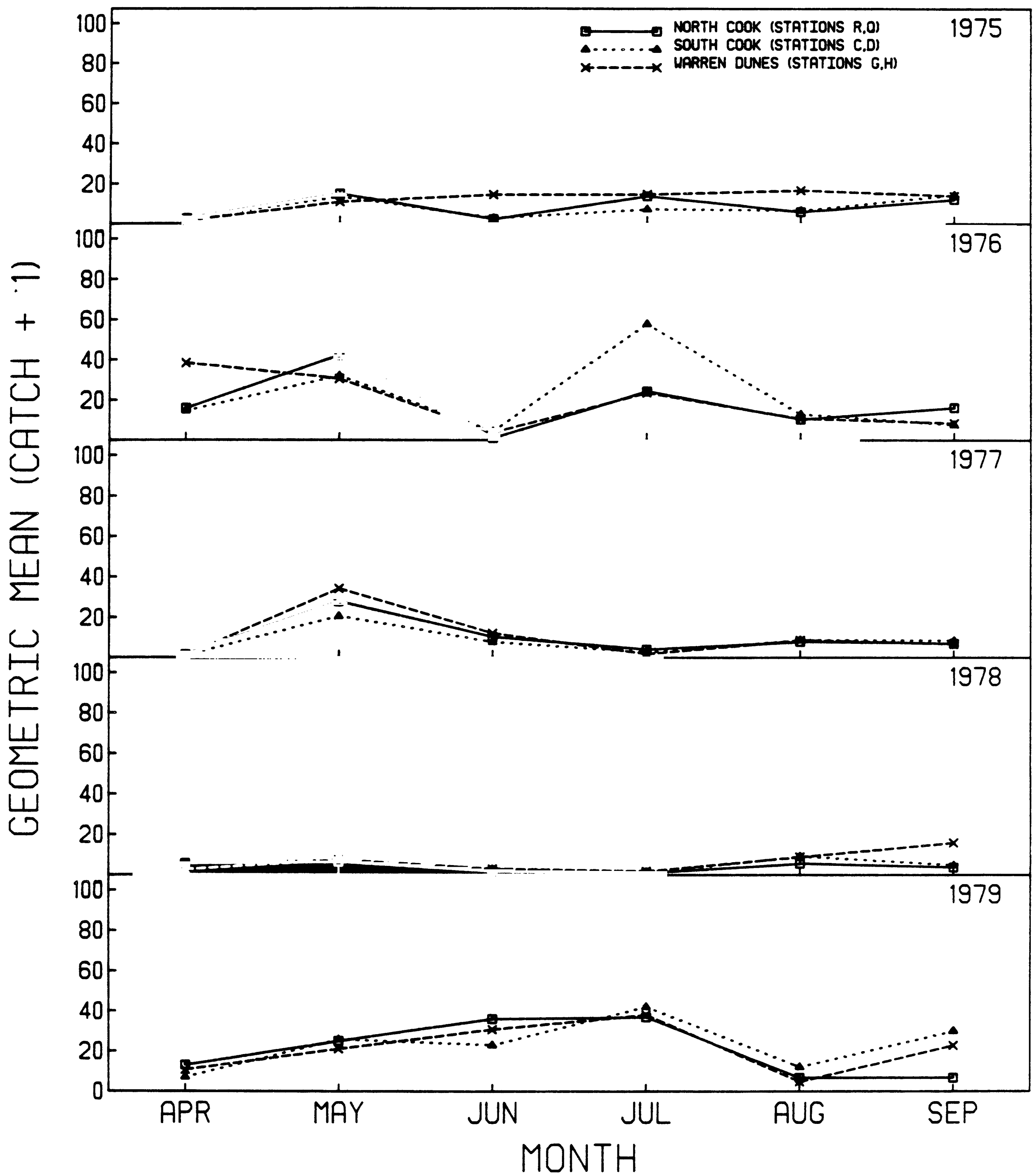


Fig. 41. Monthly geometric mean number of spottail shiners caught during operational years 1975-1979 by standard series and stations R and Q gillnetting in Cook Plant study areas, southeastern Lake Michigan.

Table 31. Analysis of variance summary for $\log_{10}$(catch + 1) of spottail shiners. Fish were seined from April to October, 1973-1979 in Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df#	Adjusted mean square##	F-statistic	Attained significance
Year	6	0.3835	1.7443	0.1105
Month	6	30.0643	136.7366	0.0000**
Station	2	0.0220	0.1002	0.9047
Time of day	1	0.1850	0.8414	0.3598
Y x M	36	2.8204	12.8277	0.0000**
Y x S	12	0.4020	1.8284	0.0433
M x S	12	0.9778	4.4468	0.0000**
Y x T	6	1.3858	6.3027	0.0000**
M x T	6	3.5737	16.2535	0.0000**
S x T	2	0.1764	0.8026	0.4492
Y x M x S	72	0.4130	1.8785	0.0001**
Y x M x T	36	1.9295	8.7758	0.0000**
Y x S x T	12	0.3136	1.4263	0.1528
M x S x T	12	0.6746	3.0681	0.0004**
Y x M x S x T	72	0.4499	2.0463	0.0000**
Within cell error	293	0.2199		

\# One degree of freedom was subtracted from the error term to correct for a missing observation where the cell mean was substituted.

\#\# Mean squares were multiplied by harmonic cell size/maximum cell size (nh/n = 0.9966) to correct for one missing observation where the cell mean was substituted.

** Highly significant (P <0.001).

any influence of plant operation upon local spottail populations. Currently, the population appears stable, periodically producing strong year classes.

Distribution and Growth by Age-group--

Spottail shiner age-size groups were identified by examination of modes in length-frequency histograms (Fig. 44). This method allowed separation of young-of-the-year (YOY, age 0), yearlings (age 1), and adults (age 2+). We were not able to distinguish age-groups beyond age 1 because of overlapping length distributions.

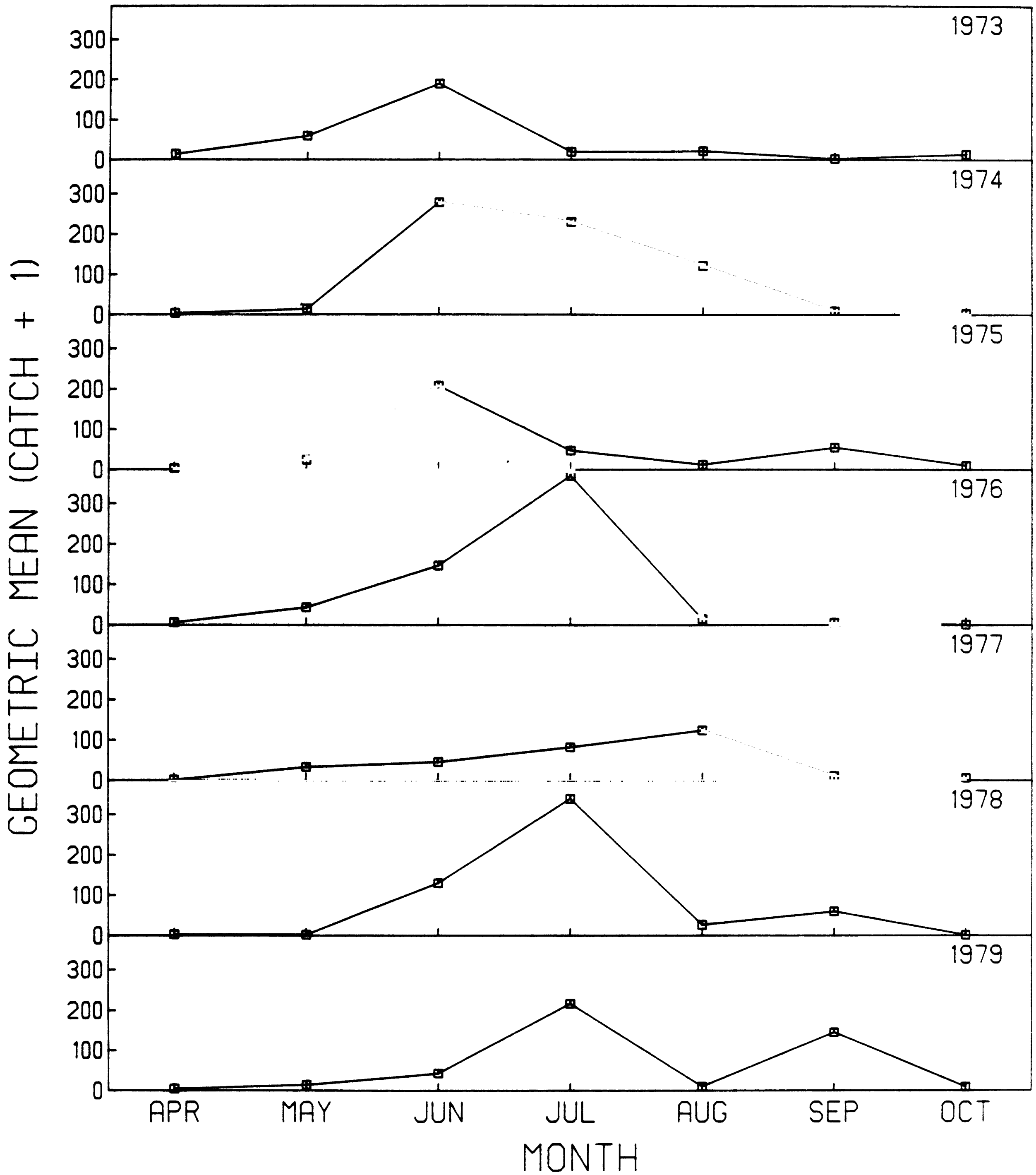


Fig. 42. Monthly geometric mean number of spottail shiners caught by standard series seining in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

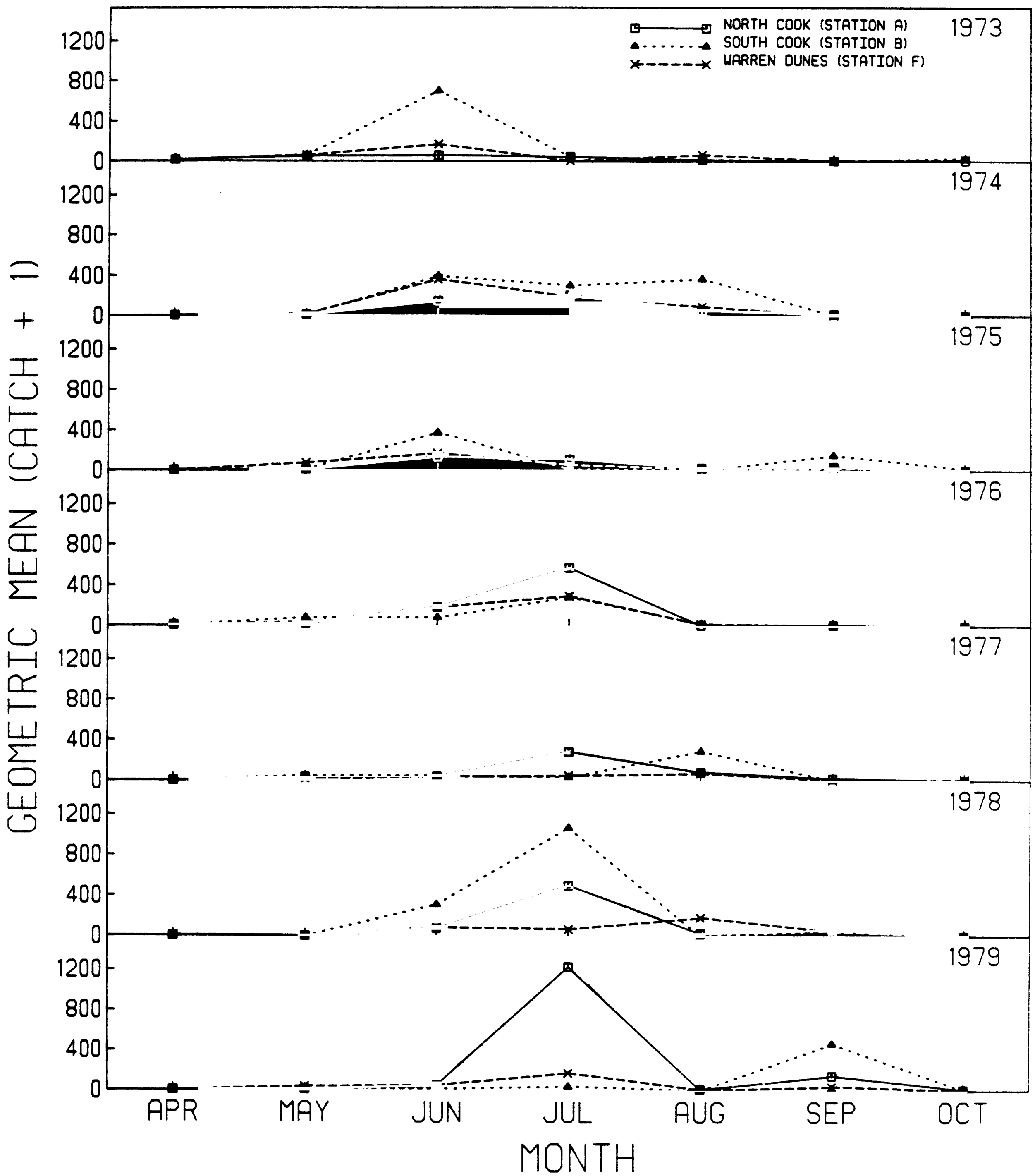


Fig. 43. Monthly geometric mean number of spottail shiners caught by standard series seining in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

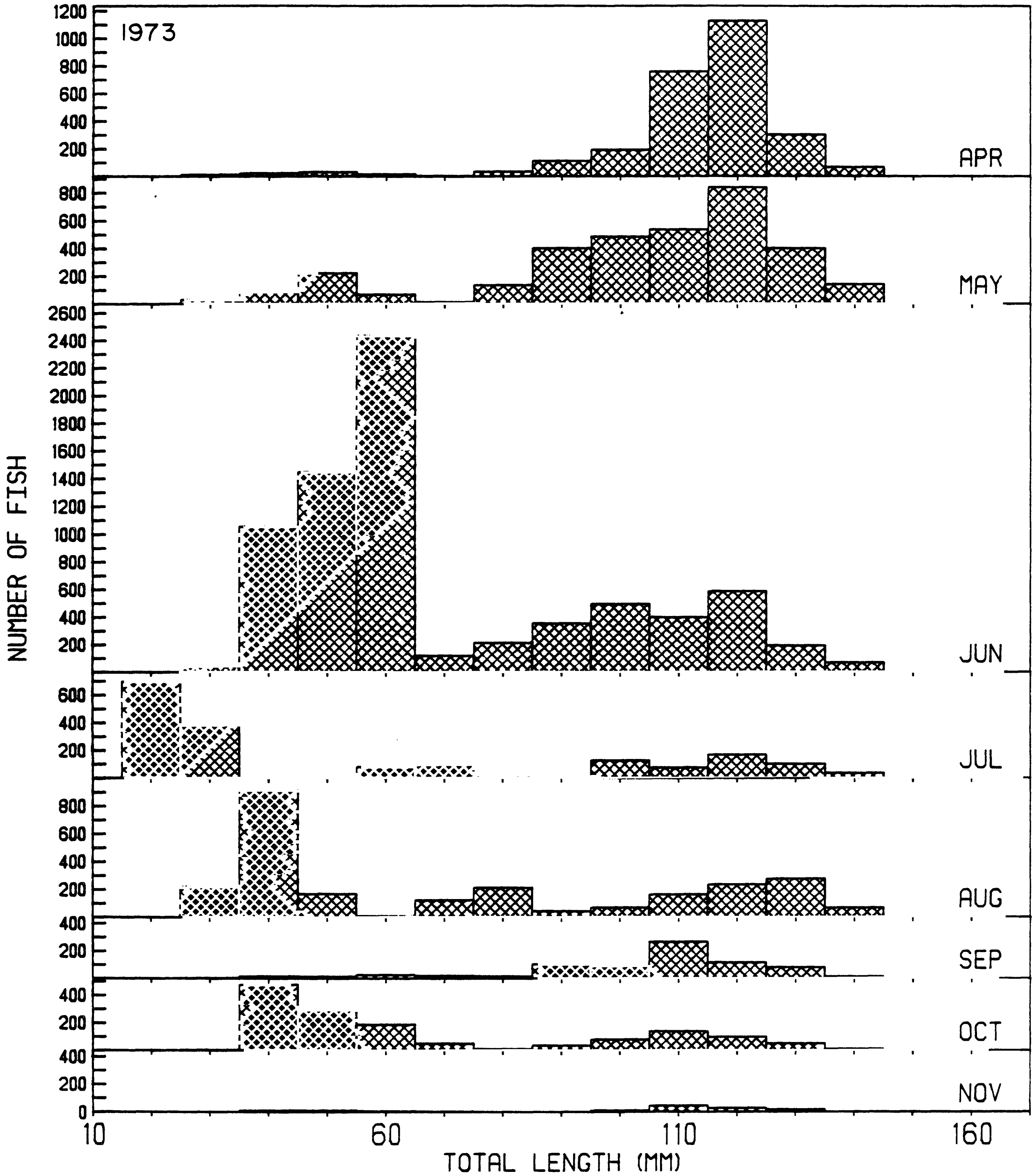


Fig. 44. Monthly length-frequency histograms of spottail shiners caught during 1973-1979 by standard series trawling, gillnetting, and seining in Cook Plant study areas, southeastern Lake Michigan.

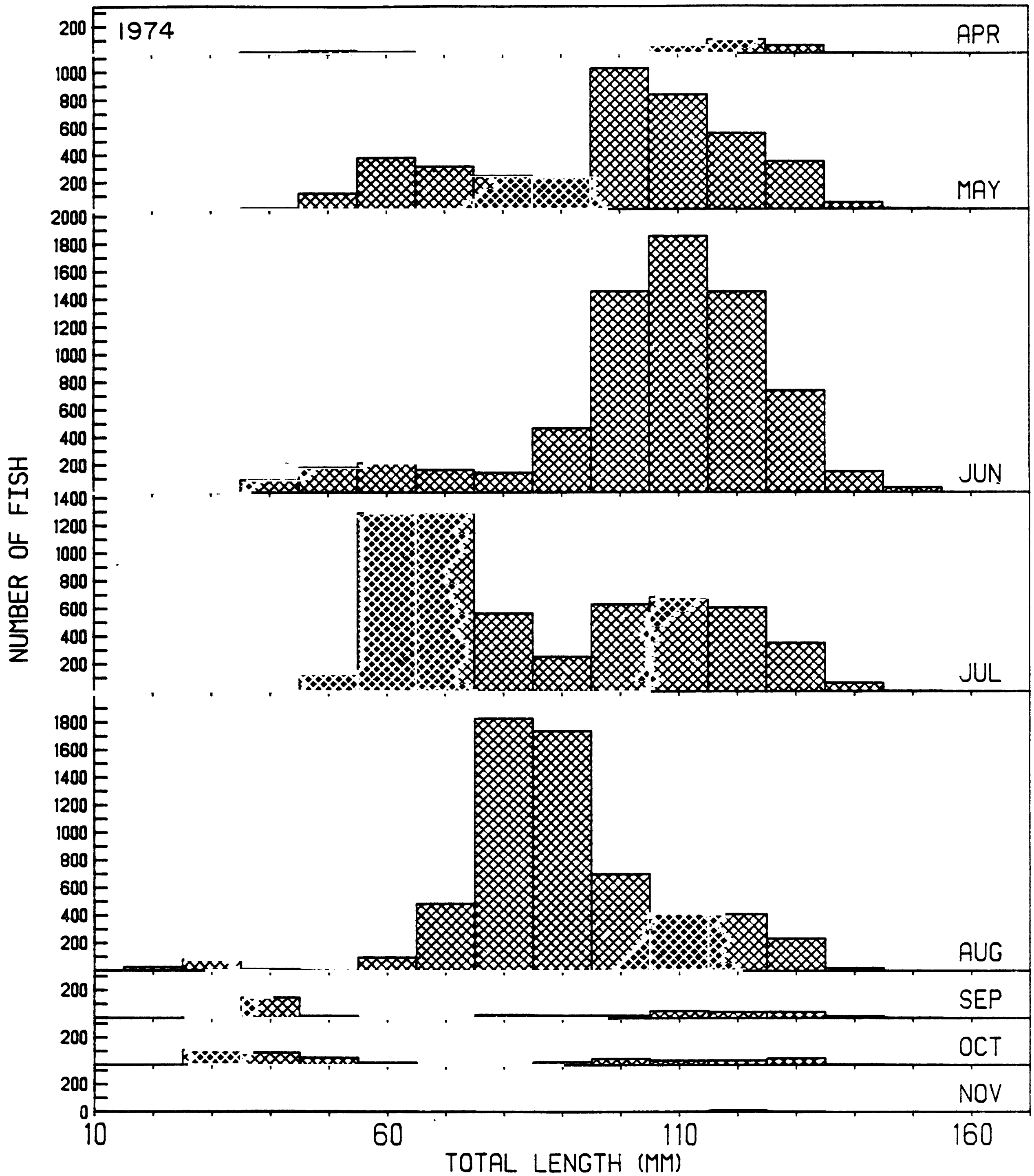
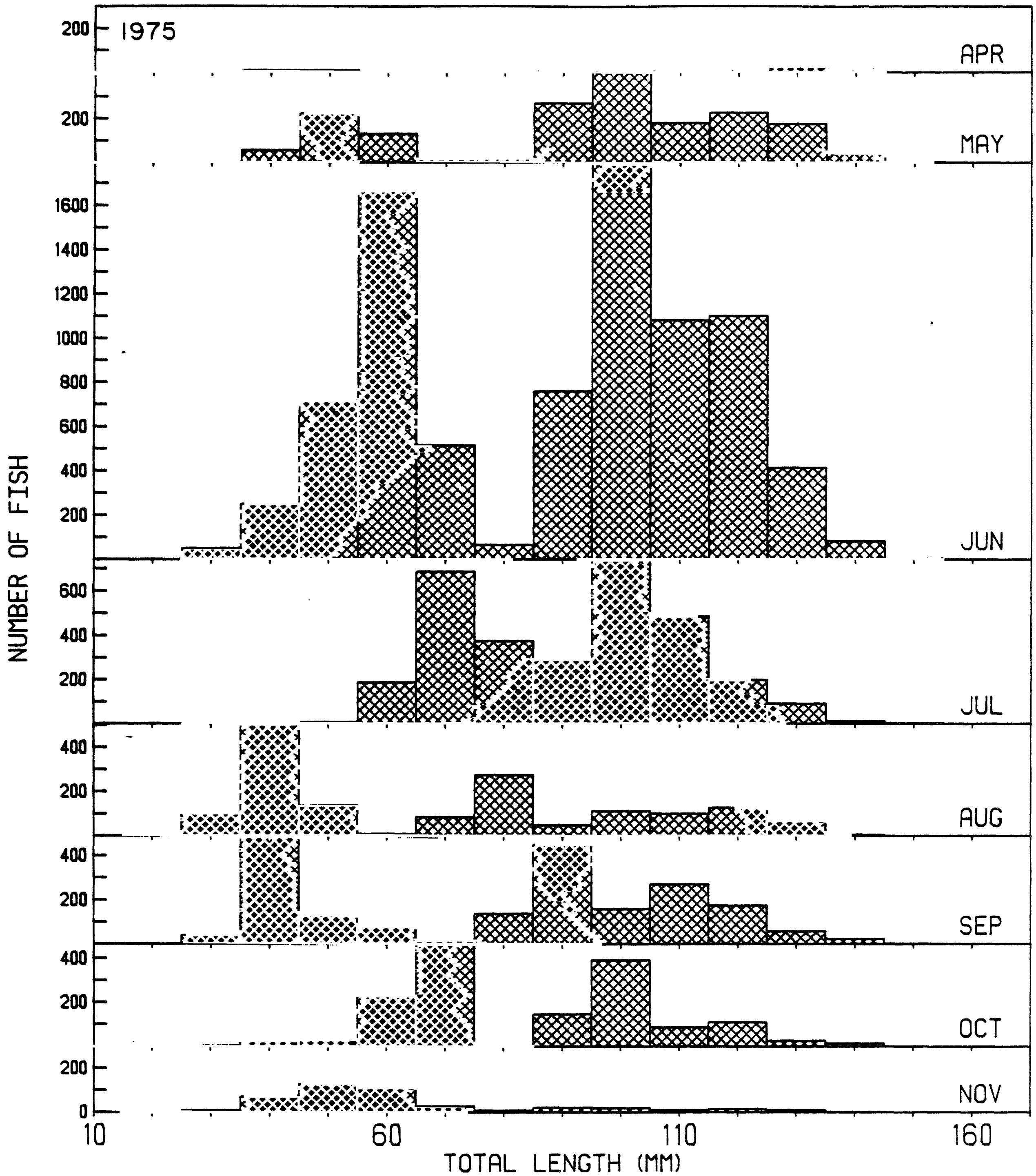


Fig. 44. Continued.



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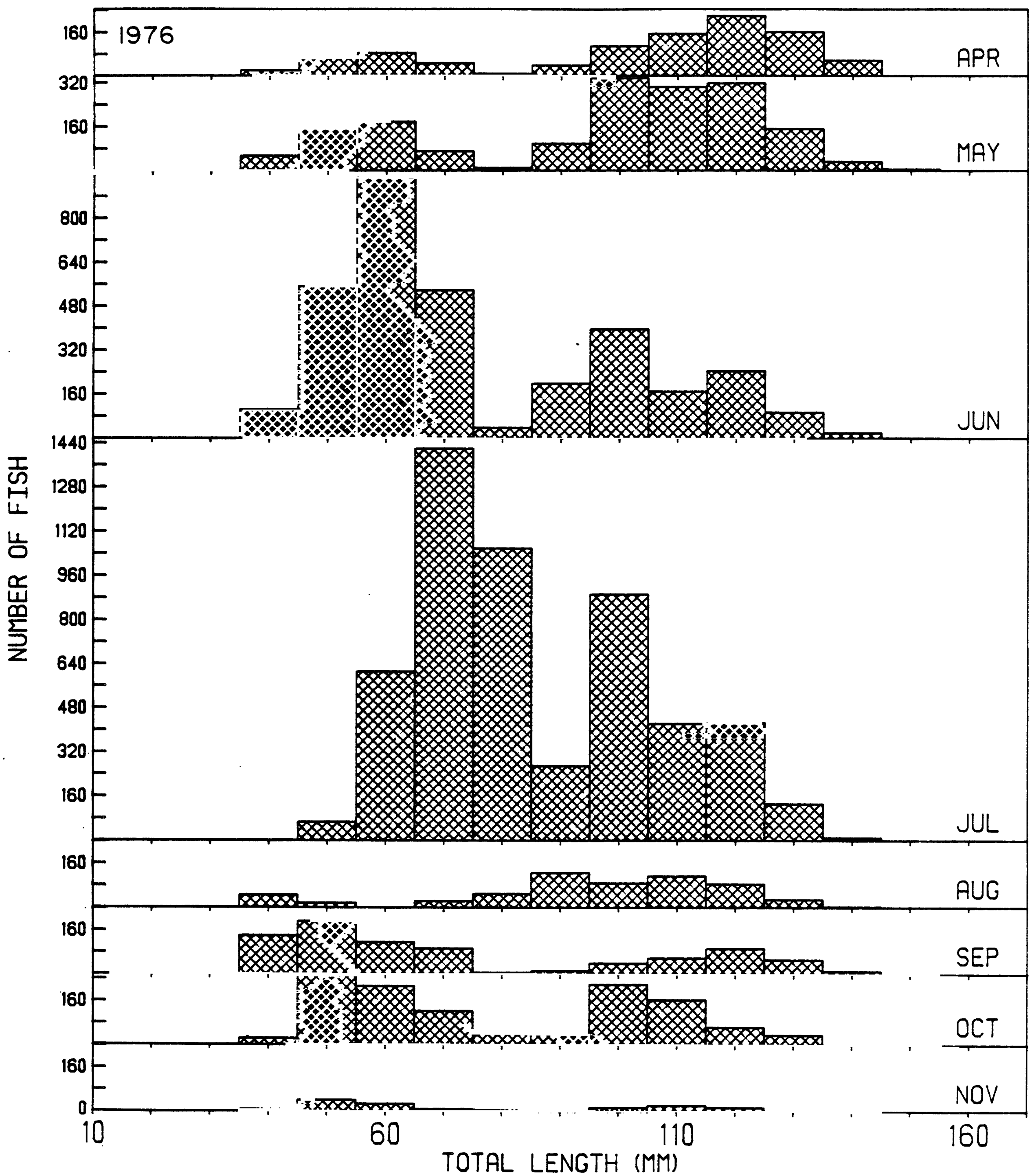

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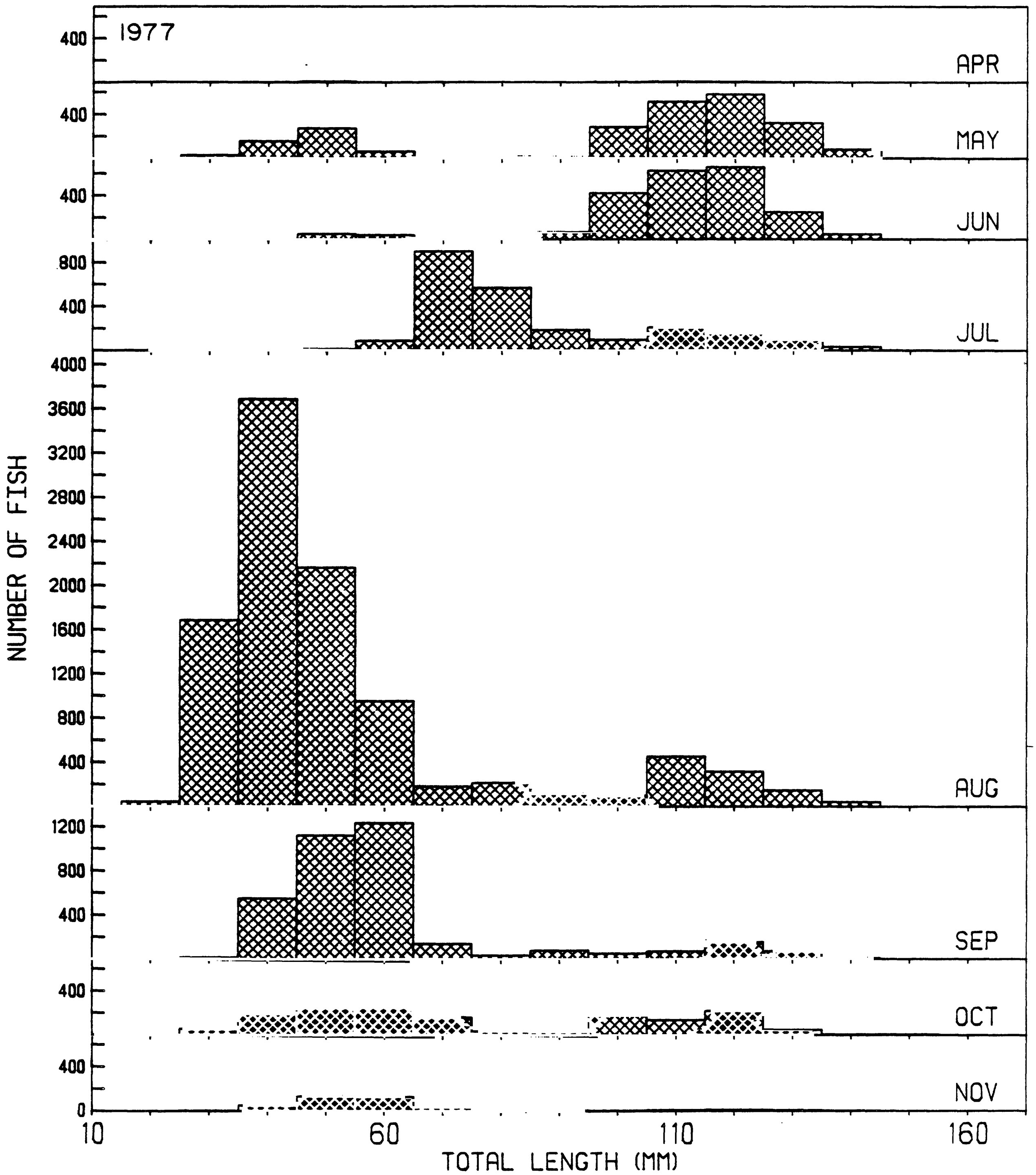

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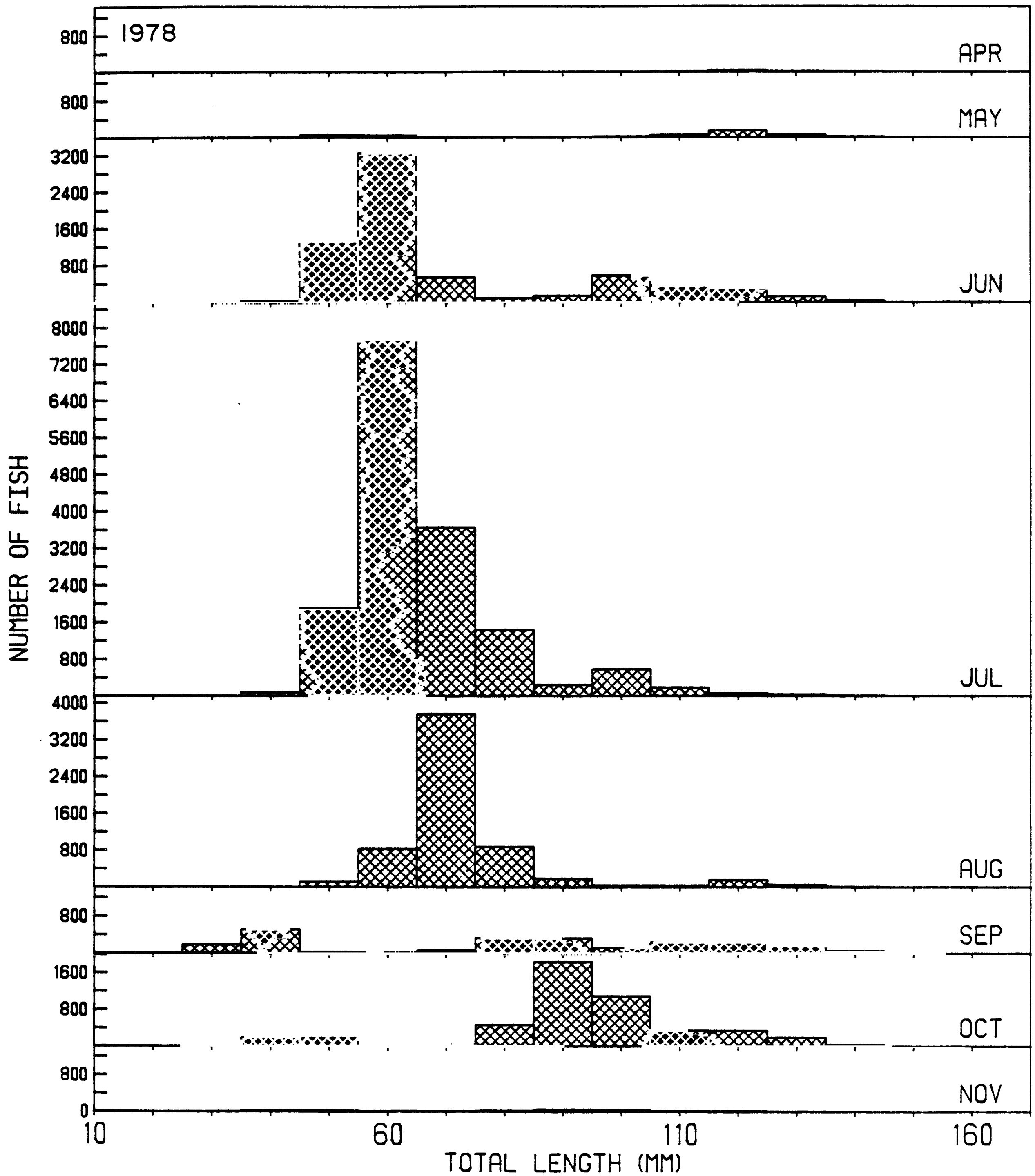


Fig. 44. Continued.

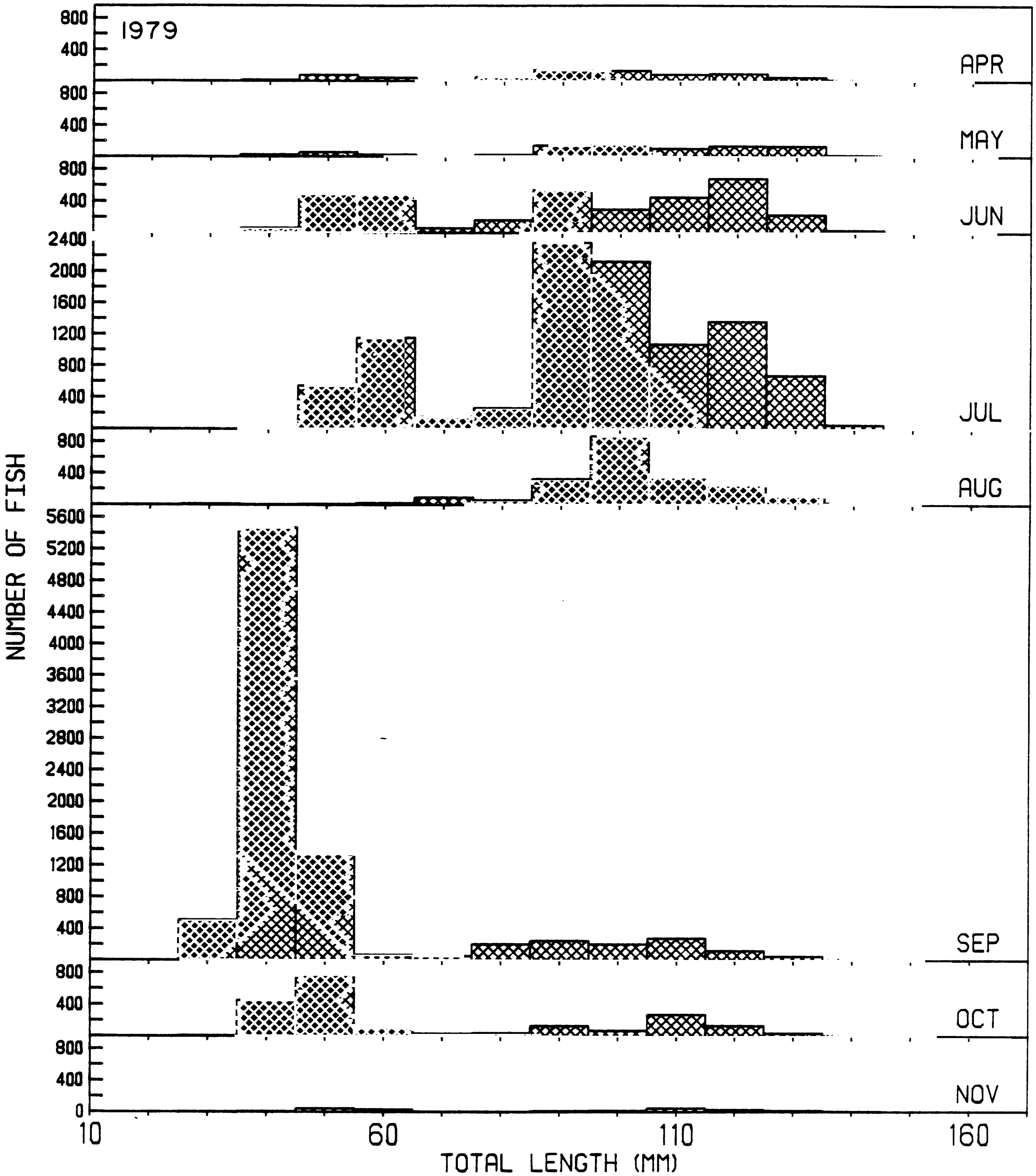


Fig. 44. Continued.

Total standard series catches of spottail shiners fluctuated substantially among age-groups and on an annual basis. Strong year classes were produced in 1977 and 1979 and weak year classes in 1974 and 1978. Standard series catches of YOY spottail shiners appeared to be a good indicator of variation in year-class strength. A rank test for correlation (Arkin and Colton 1970) indicated that YOY catch was a good predictor of yearling abundance (Spearman's coefficient = 0.85; $P<0.05$) and examination of trawl, gill net, and seine data indicated that when large year classes (1977, 1979) were recruited, significant effects would occur in the Year factor of ANOVA analysis for spottail shiner populations.

Young-of-the-year--Spottail shiner YOY were collected consistently by standard series fishing gear in all years. They were first collected in either July (1973, 1977) ranging in length from 17 to 38 mm, August (1974-1976, 1979) ranging in length from 18 to 68 mm, or September (1978) from 22 to 58 mm. In some years the mean lengths of individuals in a cohort decreased in the fall (Fig. 45). This was ascribed to (1) extended spawning and recruitment of smaller individuals to our gear late in summer or fall, (2) small sample size, or (3) larger (or earlier spawned) fish leaving the nearshore area for deeper water. For these reasons we chose to index growth rate for a cohort from the date of their first appearance in our gear to the month of their greatest mean length. Mean growth rates for the seven cohorts were: 0.31 mm/day (1973), 0.15 mm/day (1974), 0.26 mm/day (1975), 0.24 mm/day (1976), 0.26 mm/day (1977), 0.15 mm/day (1978), and 0.22 mm/day (1979). Increased growth appeared to be related to water temperatures. In 1973, the year of greatest growth rate, June-August water temperatures were 6% above the mean for 1973-1979. In 1974 and 1978, the 2 years of poorest YOY growth, water temperature means were 6% and 11.5% below the 7-year mean.

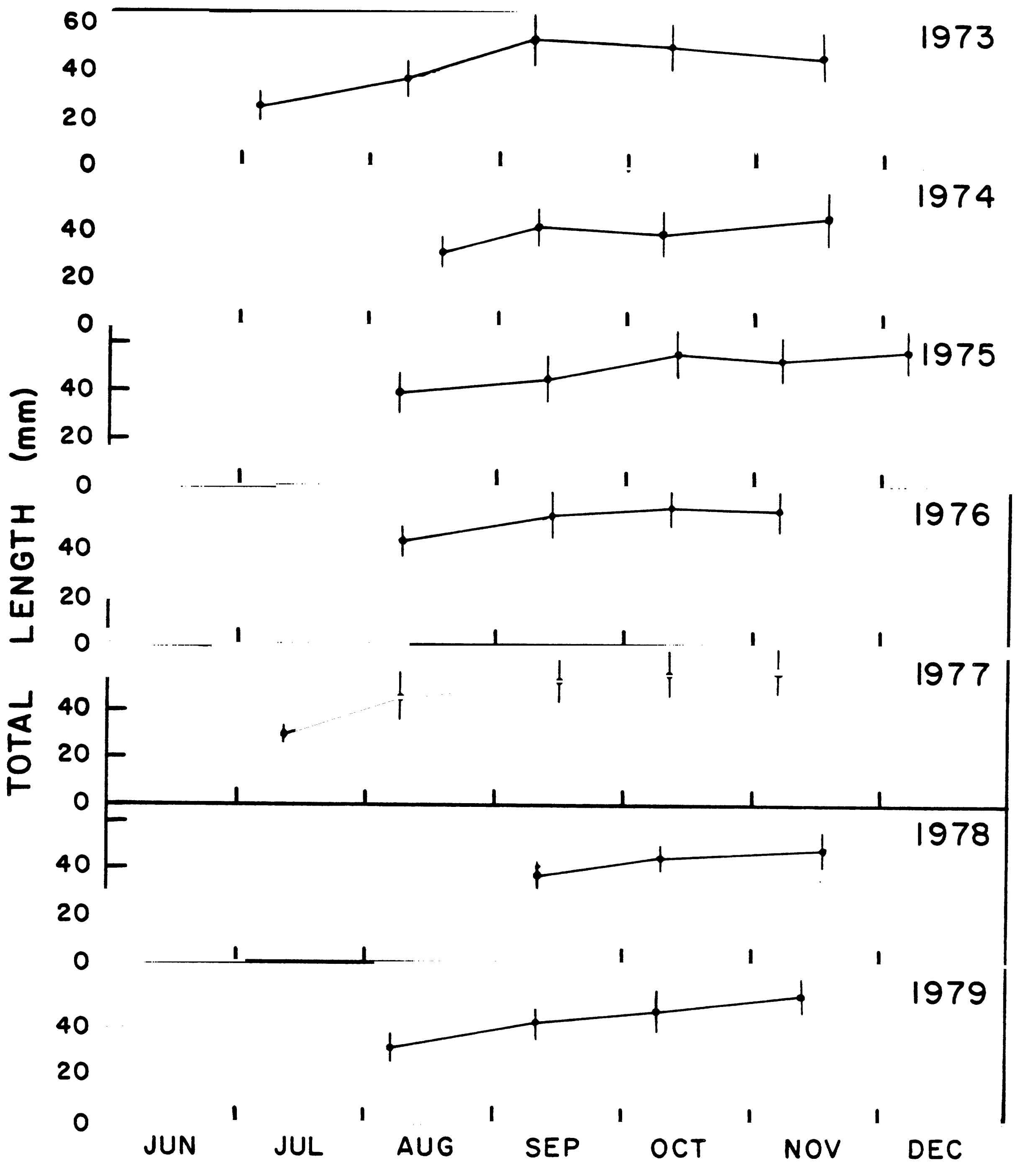


Fig. 45. Mean total length (± one standard deviation) of young-of-the-year spottail shiners caught during 1973-1979 by standard series gillnetting, trawling, and seining in Cook Plant study areas, southeastern Lake Michigan.

Yearlings--Yearlings were collected throughout the sampling year (April to November) from 1973 to 1979. Growth rates fluctuated seasonally as well as annually (Fig. 46). In April, yearlings ranged in length from 28 to 84 mm. Growth rates of YOY were a poor predictor of yearling growth potential and there appeared to be a tendency for slower growing YOY cohorts to "catch up" to an average mode of growth by the fall of their second year.

Spottail shiner yearling growth rates (June-August) were: 0.30 mm/day (1973 year class), 0.45 mm/day (1974 year class), 0.47 mm/day (1975 year class), 0.42 mm/day (1976 year class), 0.19 mm/day (1977 year class), and 0.27 (1978 year class). Two faster growing YOY cohorts (1973 and 1977) exhibited slower growth as yearlings. The 1978 cohort continued to be characterized by relatively slow growth through age 1. We suspect that both temperature and density-related factors influenced the previously mentioned spottail shifting growth patterns of YOY and yearlings. Lower water temperatures in 1974 and 1978 (6% and 11.6% decreases, respectively, in June-August temperatures) appeared to have depressed growth rates of both YOY and yearling spottails. Additionally, during the same periods (1974 and 1978), standard series catches of yearling spottails were the highest recorded, thus suggesting the possibility of increased competition within the cohorts. The 1978 cohort exhibited slow growth as both YOY and yearlings. We attribute this to cooler water and competition from the larger 1977 year class.

Adults--The age-length characteristics of the spottail shiner population in southeastern Lake Michigan appeared stable. The changes or shifts from 1973 to 1979 can be attributed to the recruitment of variable-sized year classes to the population. No substantial changes in the length-frequency distributions were discerned between Cook Plant and reference areas. We found

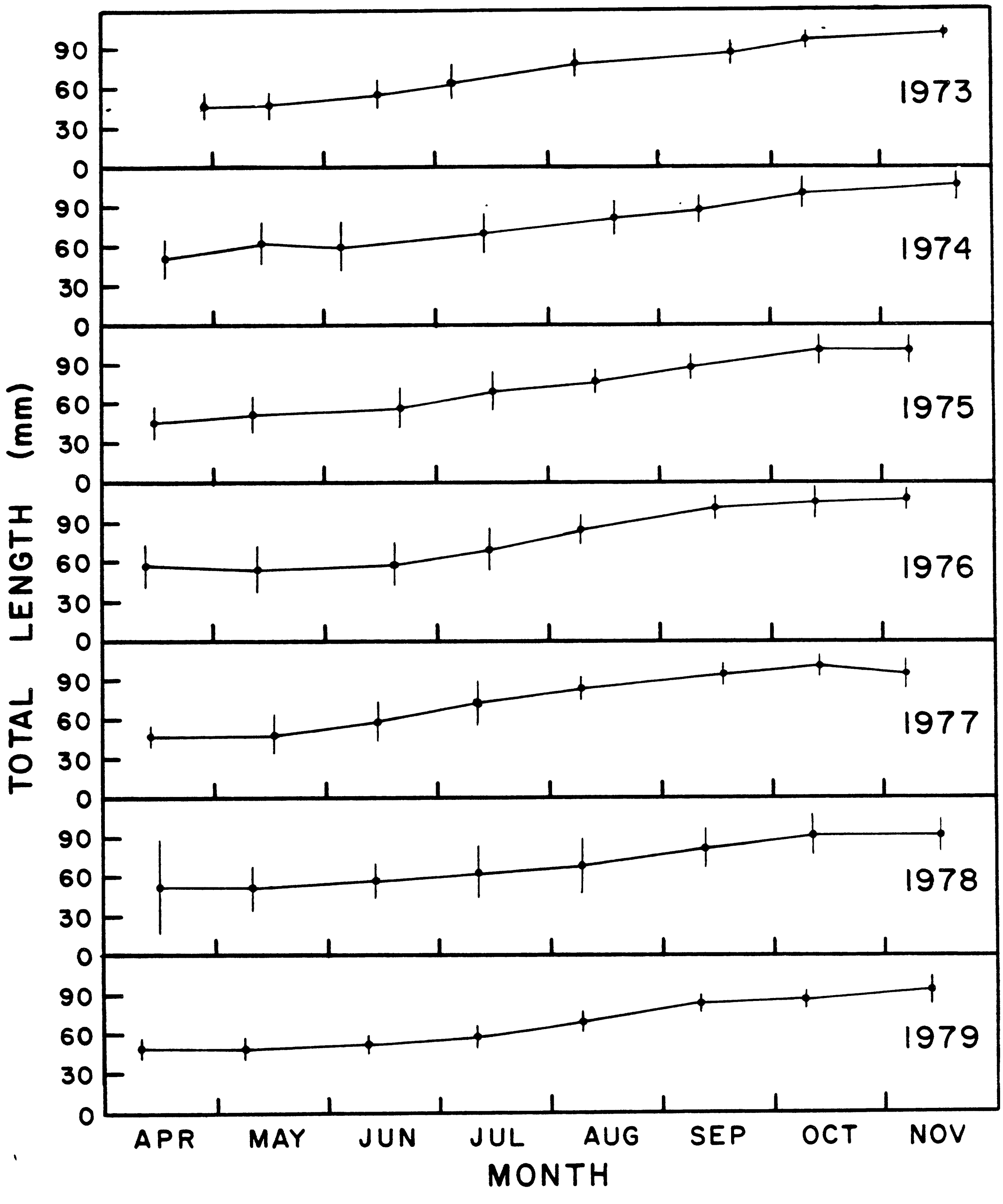


Fig. 46. Mean total length (± one standard deviation) of yearling spottail shiners caught during 1973-1979 by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan.

that most (>90%) female spottail shiners mature by 87 mm TL and most (>90%) males mature by 89 mm TL. Both sexes probably first spawn at age 2. The length-weight relationship for males ($y = 3.05x - 5.17$; $n = 9073$) and females ($y = 3.09x - 5.24$; $n = 17,485$) were not substantially different. Immature fish exhibited a length-weight relationship of $y = 3.10x - 5.29$; $n = 10,431$. There appeared to be no differences in adult spottail shiner growth patterns between Cook Plant and Warren Dunes areas.

In summary, there were no differences among YOY, yearlings, or adult spottail shiner growth rates, length-weight relationships, or length-frequency distributions between Cook Plant and reference stations. Growth patterns of YOY and yearling spottails appeared to be related to density-dependent factors and the nearshore thermal regime. Year-class strength was often established by the fall of the cohort's first year. Growth compensation often occurred by the fall of the cohort's second year.

Other Considerations--

Myxosporidian parasitism appears to be a minor affliction of spottail shiner populations in southeastern Lake Michigan. Parasitized females outnumbered males by more than a 2:1 ratio. The incidence of parasitism was greatest in June and July, and we believe it is related to increased water temperatures and the stress of spawning or spread by the aggregation of adults for spawning. No significant differences in parasitism were noted between Cook Plant and reference areas.

Spawning activity of spottail shiners in Lake Michigan varies considerably from year to year (Wells and House 1974). Generally, rapidly increasing temperatures induce earlier spawning which can occur over an extended

period. Spottail shiner larvae first appeared in entrainment samples in early to mid-June (all years) and were present until late July (1977), August (1975, 1978, 1979), or even October (1976). Peak abundance of entrained spottail larvae generally occurred in July (1975, 1976, 1978), but occurred as early as June (1977) and as late as August (1979). Gonad condition of adults confirmed the peak June-July spawning period (Table 32). The highest frequency of spent females usually occurred in July or August of most years.

Spottail shiner distribution in Lake Michigan has been described in the literature (Wells and House 1974, Wells 1968). Wells (1968) found spottail shiners distributed at depths usually less than 13 m in spring and summer at temperatures from 13°C to at least 22°C. We have collected spottails in the beach zone in mid-winter at temperatures near freezing and in late summer at temperatures over 28°C (Fig. 47). The greatest overall abundance of spottail shiners in standard series catches occurred at 23°C. Catches at these temperatures probably consisted largely of yearling and YOY fish collected in the beach zone or by trawls in late summer. Peaks in catch also occurred at 11°C and 15°C. These catches probably coincided with spottail shiner spawning activity and consisted of mature adults. Most immature spottails (YOY and yearlings) were collected at warmer temperatures in late summer, and most adults were collected at temperatures in the mid-teens.

Wells (1968) noted that larger spottail shiner adults tended to dominate catches in cooler (deeper) areas. We also observed this trend (Fig. 48). However, we should note that all age-groups were not present in our sampling area throughout the range of temperature fished. Smaller spottails were most often collected in late summer at temperatures in excess of 20°C. Larger fish (>120 mm) were usually collected at temperatures near 15°C. In summary,

Table 32. Number of ripe and spent spottail shiners caught by standard series trawling, gillnetting, and seining in Cook Plant study areas, southeastern Lake Michigan, 1973-1979. F = female, M = male, ND = no data.

Year	Sex	Gonad condition	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	F	Ripe	7	159	289	251	25	0	0	1	0	0
		Spent	0	0	0	68	69	123	70	6	0	0
	M	Ripe	1	30	52	9	8	1	0	0	0	0
		Spent	0	0	0	45	45	65	20	3	0	0
1974	F	Ripe	10	30	259	363	167	2	0	2	0	0
		Spent	0	1	0	26	158	132	33	5	0	0
	M	Ripe	5	8	12	11	7	0	0	2	0	0
		Spent	0	0	0	7	72	53	3	0	0	0
1975	F	Ripe	0	4	73	196	19	1	2	0	8	1
		Spent	0	0	3	43	24	6	18	1	0	0
	M	Ripe	0	0	2	15	9	0	1	0	0	0
		Spent	0	0	0	27	7	1	13	1	0	0
1976	F	Ripe	0	34	209	114	65	0	0	1	0	ND
		Spent	0	0	8	18	55	29	25	4	0	ND
	M	Ripe	0	10	31	7	8	4	0	0	0	ND
		Spent	0	0	1	0	11	1	12	0	0	ND
1977	F	Ripe	0	0	161	163	20	2	0	1	1	0
		Spent	0	0	3	13	55	55	8	0	0	0
	M	Ripe	0	0	34	32	6	1	0	0	0	0
		Spent	0	0	0	32	4	17	2	0	0	0
1978	F	Ripe	ND	8	15	182	25	10	1	2	2	ND
		Spent	ND	0	0	8	16	39	7	1	0	ND
	M	Ripe	ND	2	0	15	5	1	0	2	0	ND
		Spent	ND	0	0	18	17	21	0	0	0	ND
1979	F	Ripe	ND	0	10	241	126	1	0	0	0	ND
		Spent	ND	0	0	12	191	74	2	0	0	ND
	M	Ripe	ND	0	0	7	51	15	0	0	0	ND
		Spent	ND	0	0	4	99	41	0	0	0	ND

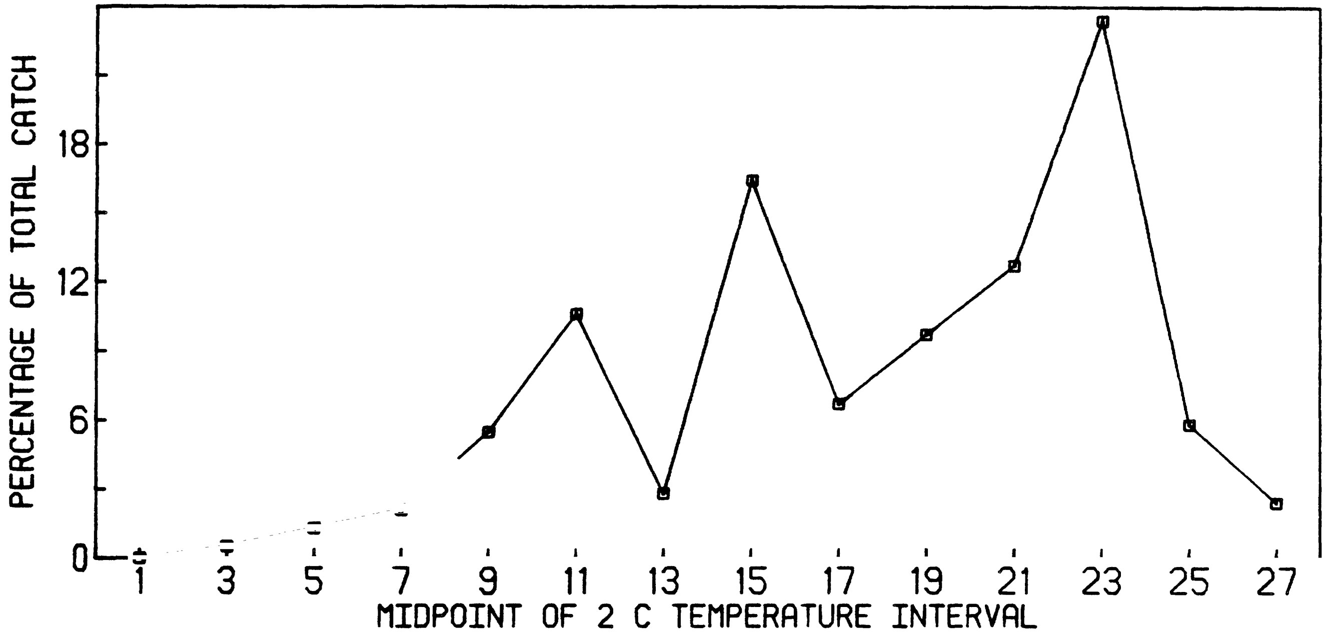


Fig. 47. Percentage of the combined total standard series catch of spottail shiners collected during 1973-1979 from various temperatures in Cook Plant study areas, southeastern Lake Michigan.

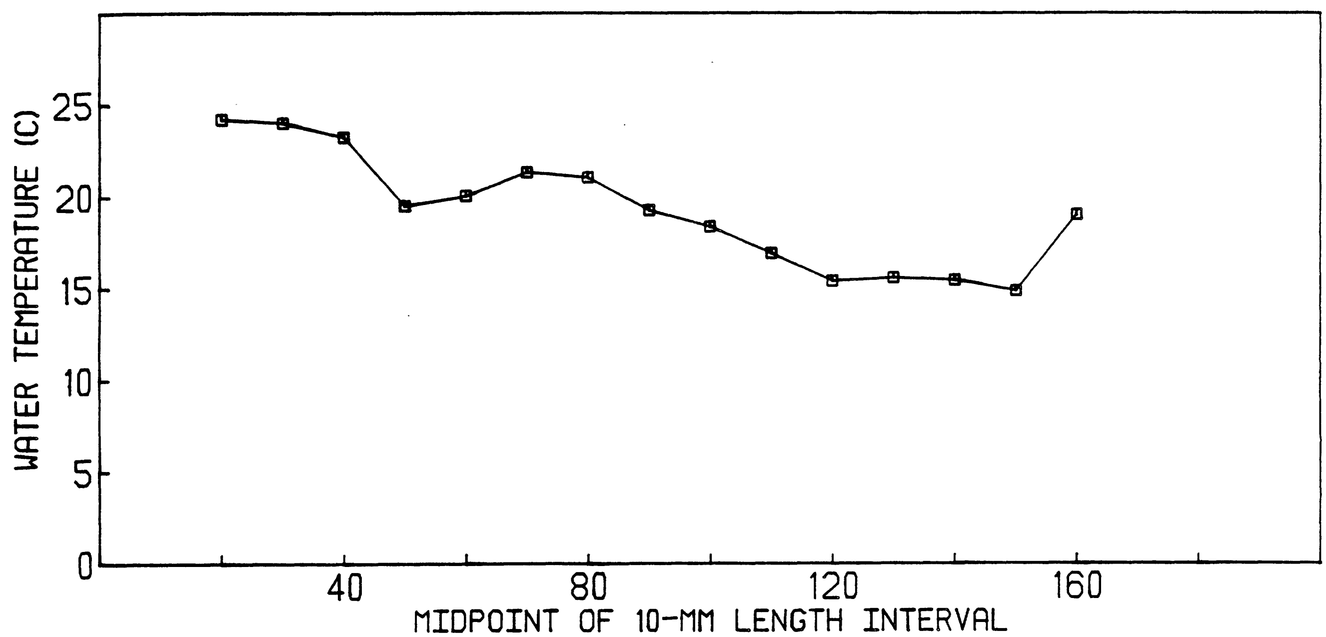


Fig. 48. Mean temperature at which various sizes of spottail shiners were caught during 1973-1979 by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan.

spottail shiner distribution in relation to temperature was usually the result of differential use of the nearshore areas by various age-groups rather than a definitive temperature preference. Adult fish usually comprised a greater percentage of the catch in spring and early summer when lower temperatures occurred. YOY were most abundant and susceptible to our gear in late summer and early fall when temperatures were approaching their annual maximums.

Trout-perch--

Introduction--

The trout-perch is an indigenous, moderately abundant species inhabiting Lake Michigan. In addition, trout-perch are an appropriate size to be potentially preyed upon by piscivorous fishes. Scott and Crossman (1973) report that trout-perch are consumed by burbot, sauger, yellow perch, and freshwater drum. In Lake Erie, they ranked trout-perch second only to emerald shiner in the diet of piscivorous fishes. Although trout-perch are not heavily consumed by predatory fishes in southeastern Lake Michigan (Jude et al. 1979), they are a source of available forage. In addition, because trout-perch are relatively abundant near the Cook Plant, they may be closely interwoven with other fish community interactions. Therefore, any plant influence on the distribution or abundance of this species may affect many other fishes in the area.

Preoperational netting at Cook and Warren Dunes areas showed trout-perch residing at intermediate depths and utilizing areas that would be proximal to the thermal plume (Jude et al. 1979). Trout-perch avoided the beach zone as evidenced by low seine catches. Nocturnal shoreward movements were also a predictable part of their behavior. Disruption of these behaviors at Cook

during operational years would be considered a possible plant effect. A large preoperational and operational data base allowed investigation of these and other possible changes in trout-perch distribution relative to the thermal plume.

Trawl Data--

Trawling accounted for 89.2% of the total trout-perch catch from 1973 through 1979, making this gear the most sensitive indicator of trout-perch abundance in the study areas. All statistical analyses of the trawl data were performed on day and night catches from June through October. Small or zero catches during other months precluded any statistical analyses.

Years--Analysis of the 1973-1979 trawl catch data showed differences among years that were highly significant (Table 33). Catches were small during 1974, 1975, and 1979. The 1973, 1976, 1977, and 1978 trout-perch catches were considerably larger. Over these 7 years, catch ranged from 765 fish in 1975 to 3,170 in 1973. Although catch fluctuated greatly, no long-term trends were evident. Scheffe's test showed no significant differences between mean trawl catches from preoperational and operational Unit 1 and Unit 2 years (1973-1974 vs. 1975-1979). In addition, there was no significant difference in mean catch between the first full year of two-unit operation and all other years (1979 vs. 1973-1978).

The significant Year effect (Table 33) is primarily the result of variation in catch among years during June, July, and August (Fig. 49). The significant Year x Month interaction (Table 33) supports this observation. Except for a large October 1978 catch, fall catches were consistently small. Because summer (June - August) is the peak spawning season of trout-perch in Lake Michigan (House and Wells 1973), they may be more often in nearshore

Table 33. Analysis of variance summary for log(catch + 1) of trout-perch. Fish were trawled from June to October, 1973-1979 in Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df#	Adjusted mean square##	F-statistic	Attained significance
Year	6	3.5194	61.1300	0.0000**
Month	4	5.2101	90.4972	0.0000**
Area	1	0.7336	12.7419	0.0004**
Depth	1	1.1150	19.3673	0.0000**
Time	1	71.0224	1,233.6238	0.0000**
Y x M	24	1.6981	29.4947	0.0000**
Y x A	6	0.1431	2.4864	0.0233
M x A	4	0.2644	4.5924	0.0013*
Y x D	6	0.7412	12.8750	0.0000**
M x D	4	1.3613	23.6443	0.0000**
A x D	1	0.0637	1.1067	0.2937
Y x T	6	0.8853	15.3769	0.0000**
M x T	4	2.1448	37.2541	0.0000**
A x T	1	0.3090	5.3679	0.0212
D x T	1	1.0173	17.6706	0.0000**
Y x M x A	24	0.2424	4.2096	0.0000**
Y x M x D	24	0.3885	6.7479	0.0000**
Y x A x D	6	0.1975	3.4307	0.0028*
M x A x D	4	0.0771	1.3387	0.2557
Y x M x T	24	0.8733	15.1694	0.0000**
Y x A x T	6	0.2689	4.6703	0.0002**
M x A x T	4	0.9955	17.2915	0.0000**
Y x D x T	6	0.7060	12.2625	0.0000**
M x D x T	4	0.1809	3.1415	0.0150
A x D x T	1	0.3024	5.2519	0.0227
Y x M x A x D	24	0.1526	2.6511	0.0001**
Y x M x A x T	24	0.2082	3.6165	0.0000**
Y x M x D x T	24	0.2006	3.4851	0.0000**
Y x A x D x T	6	0.0861	1.4957	0.1795
M x A x D x T	4	0.1333	2.3147	0.0577
Y x M x A x D x T	24	0.0874	1.5176	0.0605
Within cell error	279	0.0576		

\# One degree of freedom was subtracted from the error term to correct for a missing observation where the cell mean was substituted.

\## Mean squares were multiplied by harmonic mean cell size/maximum cell size ($nh/n = 0.9975$) to correct for one missing observation where cell mean was substituted.

** Highly significant ($P < 0.001$).

* Significant ($P < 0.01$).

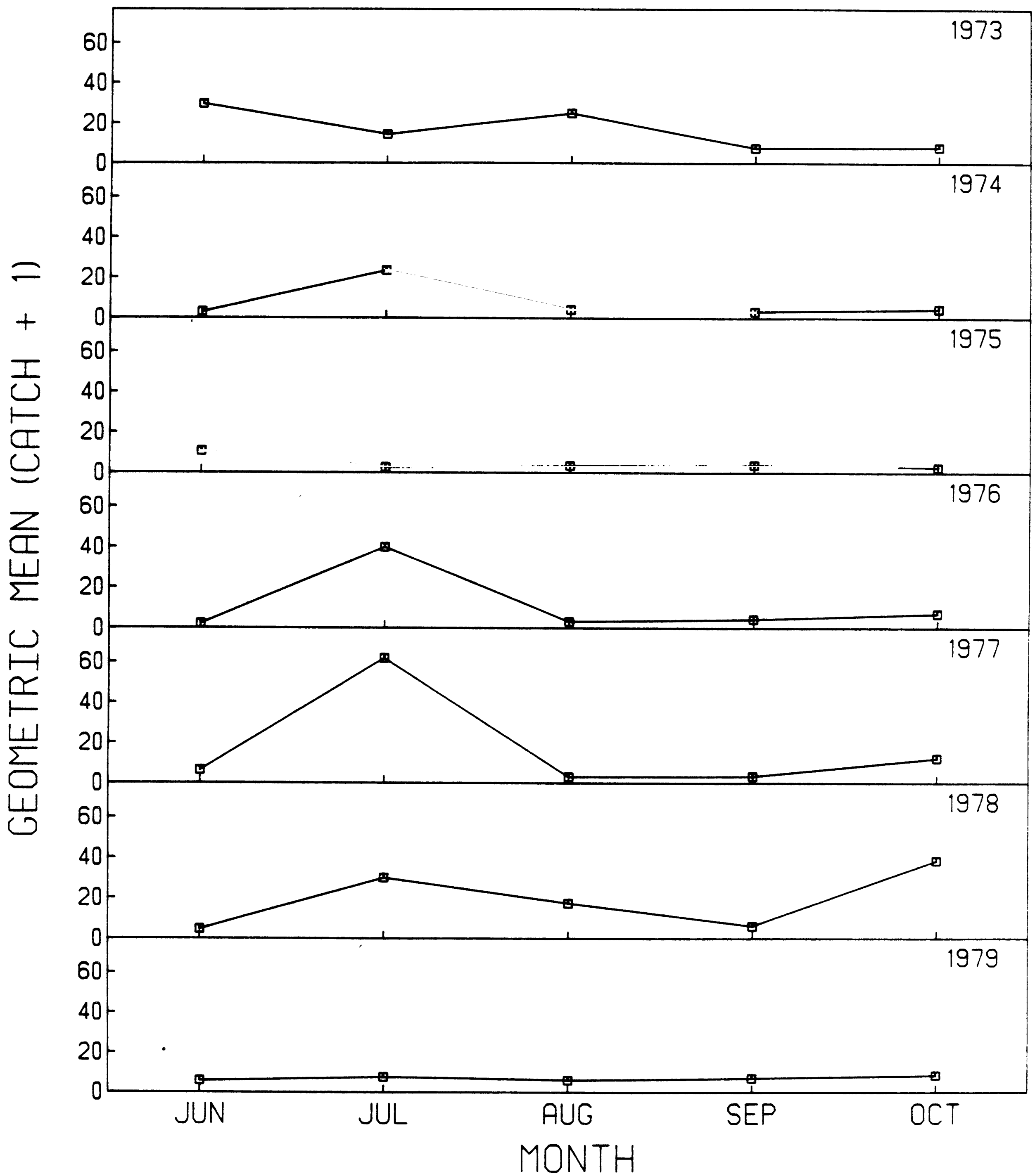


Fig. 49. Monthly geometric mean number of trout-perch caught by standard series trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

waters and vulnerable to capture. Hence, year-to-year variability in timing of spawning with the sampling schedule may explain these fluctuating catches. Other factors, including upwellings and variable year-class strength may also have contributed to the disparate catches among years. However, none of these fluctuations in catch could be attributed to plant operation.

Areas--The trawling data also revealed significant differences in trout-perch catch by area. Trout-perch were caught in greater numbers at Warren Dunes than at the Cook Plant every year except 1975. However, this seems to reflect a long-term preference for Warren Dunes over the Cook Plant area by trout-perch rather than an effect of plant operation. During operational years this pattern of catch remained similar to the preoperational pattern (Fig. 50) as evidenced by the nonsignificant Year x Area interaction.

Station R was added in 1975 to more fully assess possible area effects on trout-perch abundance since plant operation began (Fig. 51). ANOVA of 1975-1979 trout-perch catch data including station R showed all main effects and most interactions to be significant (Table 34). The highly significant Station effect could be the result of plant operation. Scheffe's test revealed that Warren Dunes station G had significantly greater mean trawl catch of trout-perch than either the north (station R) or south (station C) Cook stations. However, as previously described, this probably reflects a long-term preference by trout-perch for Warren Dunes over the Cook Plant area rather than a change since plant operation began.

Gill Net Data--

Gillnetting resulted in 6.6% of the total trout-perch catch from 1973 to 1979. ANOVA of these data were performed on night catches from May through

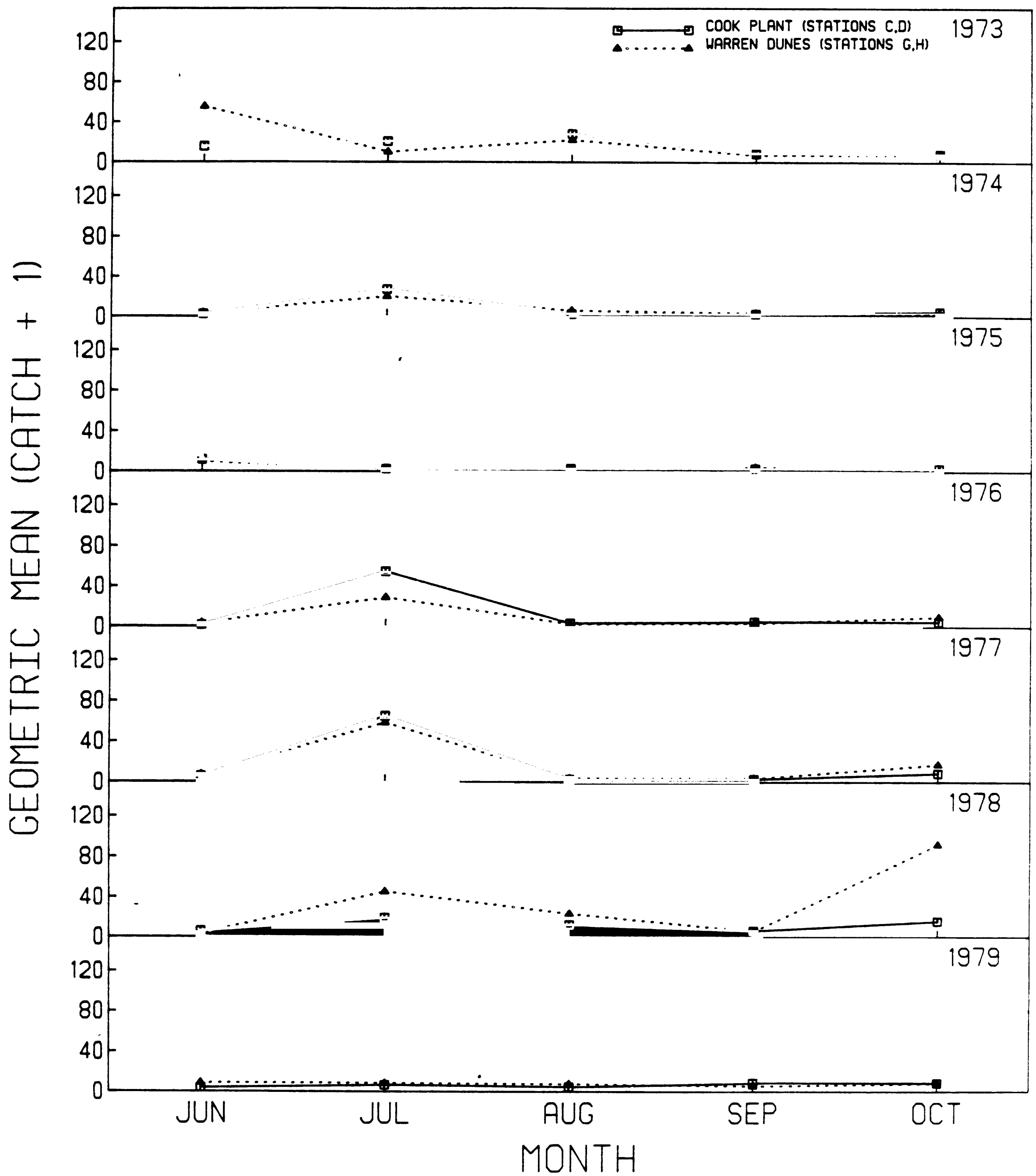


Fig. 50. Monthly geometric mean number of trout-perch caught by standard series trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

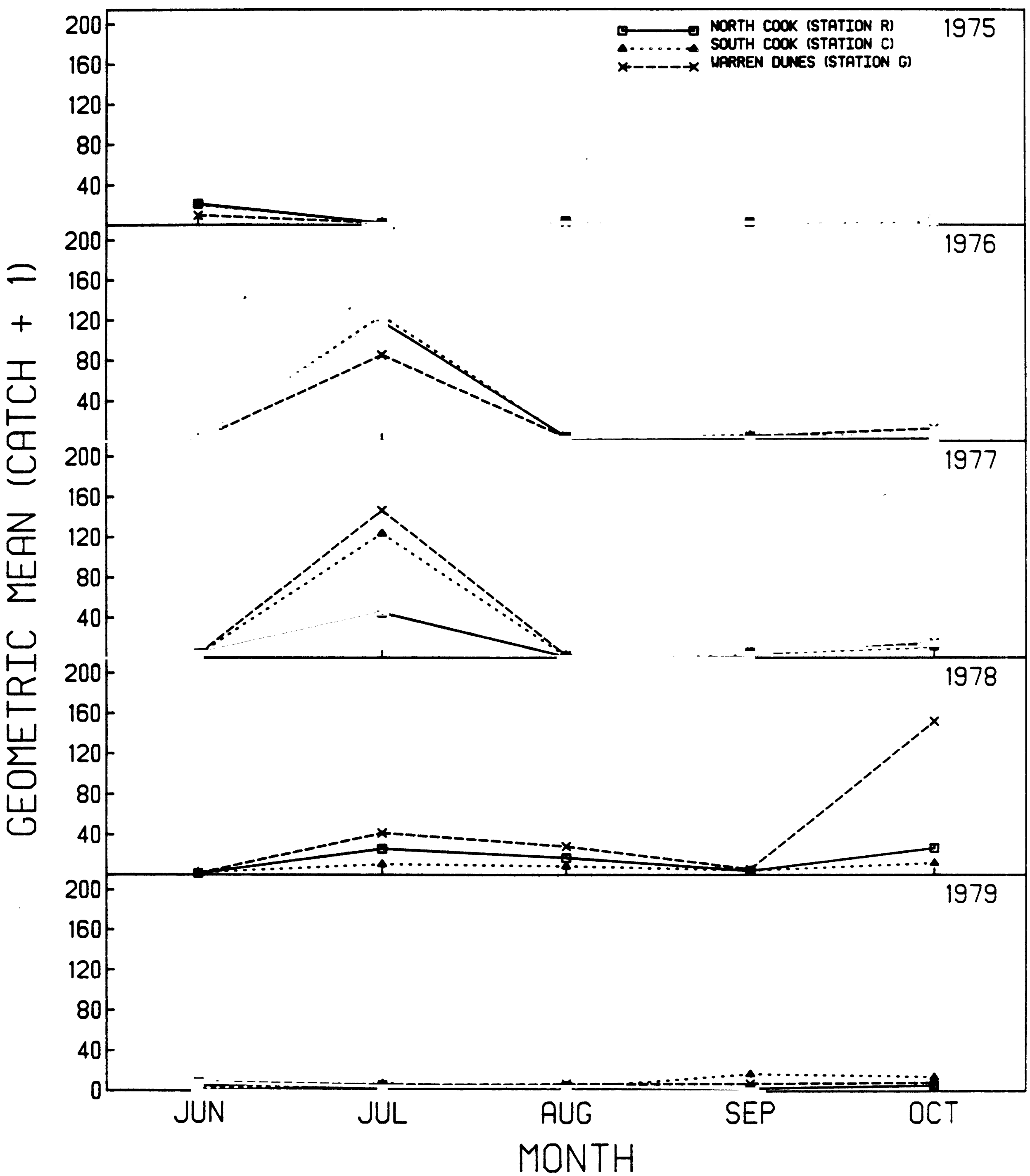


Fig. 51. Monthly geometric mean number of trout-perch caught during operational years 1975-1979 by standard series and station R trawling in Cook Plant study areas, southeastern Lake Michigan.

Table 34. Analysis of variance summary for log(catch + 1) of trout-perch. Fish were trawled from June to October, 1975-1979 in Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df	Mean square	F-statistic	Attained significance
Year	4	3.3792	62.0546	0.0000**
Month	4	6.0759	111.5748	0.0000**
Station	4	0.3813	7.0028	0.0000**
Time	1	72.7000	1,335.0271	0.0000**
Y x M	16	2.7165	49.8849	0.0000**
Y x S	16	0.2679	4.9195	0.0000**
M x S	16	0.2709	4.9742	0.0000**
Y x T	4	1.4810	27.1961	0.0000**
M x T	4	2.4524	45.0351	0.0000**
S x T	4	0.1792	3.2903	0.0119
Y x M x S	64	0.2398	4.4032	0.0000**
Y x M x T	16	0.9389	17.2412	0.0000**
Y x S x T	16	0.1711	3.1420	0.0001**
M x S x T	16	0.2708	4.9733	0.0000**
Y x M x S x T	64	0.1920	3.5260	0.0000**
Within cell error	250	0.0544		

** Highly significant (P <0.001).

September. Day catches and catches during April and after September were too small to permit parametric analysis.

Years--In contrast to trawl catches, gill net catches among years did not vary significantly (Table 35). Total catch fluctuated little among years, ranging from 74 trout-perch in 1975 to 260 in 1973. However, there was considerable fluctuation among months causing this to be the only significant main effect. The pattern of monthly catches also varied widely year to year producing a significant Year x Month interaction (Fig. 52). The presence or absence of a peak catch in July seems to account for much of this variability. These fluctuations may have been caused by seasonal temperature differences

Table 35. Analysis of variance summary for log(catch + 1) of trout-perch. Fish were gillnetted at night from May to September, 1975-1979 at Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df	Mean square	F-statistic	Attained significance limit
Year	6	0.0971	1.7728	0.1475
Month	4	0.6640	12.1278	0.0000**
Area	1	0.0824	1.5051	0.2318
Depth	1	0.4082	7.4560	0.0117
Y x M	24	0.5192	9.4833	0.0000**
Y x A	6	0.2074	3.7877	0.0085*
M x A	4	0.1422	2.5971	0.0618
Y x D	6	0.1093	1.9956	0.1060
M x D	4	0.2127	3.8853	0.0143
A x D	1	0.0160	0.2927	0.5935
Y x M x A	24	0.0868	1.5870	0.1325
Y x M x D	24	0.1410	2.5763	0.0121
Y x A x D	6	0.1198	2.1888	0.0797
M x A x D	4	0.0564	1.0306	0.4118
Y x M x A x D#	24	0.0547		

** Highly significant (P <0.001).
* Significant (P <0.01).
# The Y x M x A x D interaction was assumed to be zero, and its mean square was treated as the within cell error mean square.

among years during the sampling period or upwellings. However, none of these fluctuations appeared attributable to plant operation.

Areas--Area was also not found to have any significant effect on catch based upon analysis of the gill net data. However, a significant Year x Area interaction resulted from Warren Dunes catches exceeding Cook Plant catches every year except 1977 and 1979 (Fig. 53). Analyzing these data using Scheffe's test showed no significant catch differences during preoperational years and Unit 1 operational years (1973-1974 vs. 1975-1978) or between preoperational and all operational years (1973-1974 vs. 1975-1979) at Cook Plant (C,D) or Warren Dunes (G,H) stations. In addition, no significant differences in catch were found between one- and two-unit operational years (1975-1978 vs. 1979).

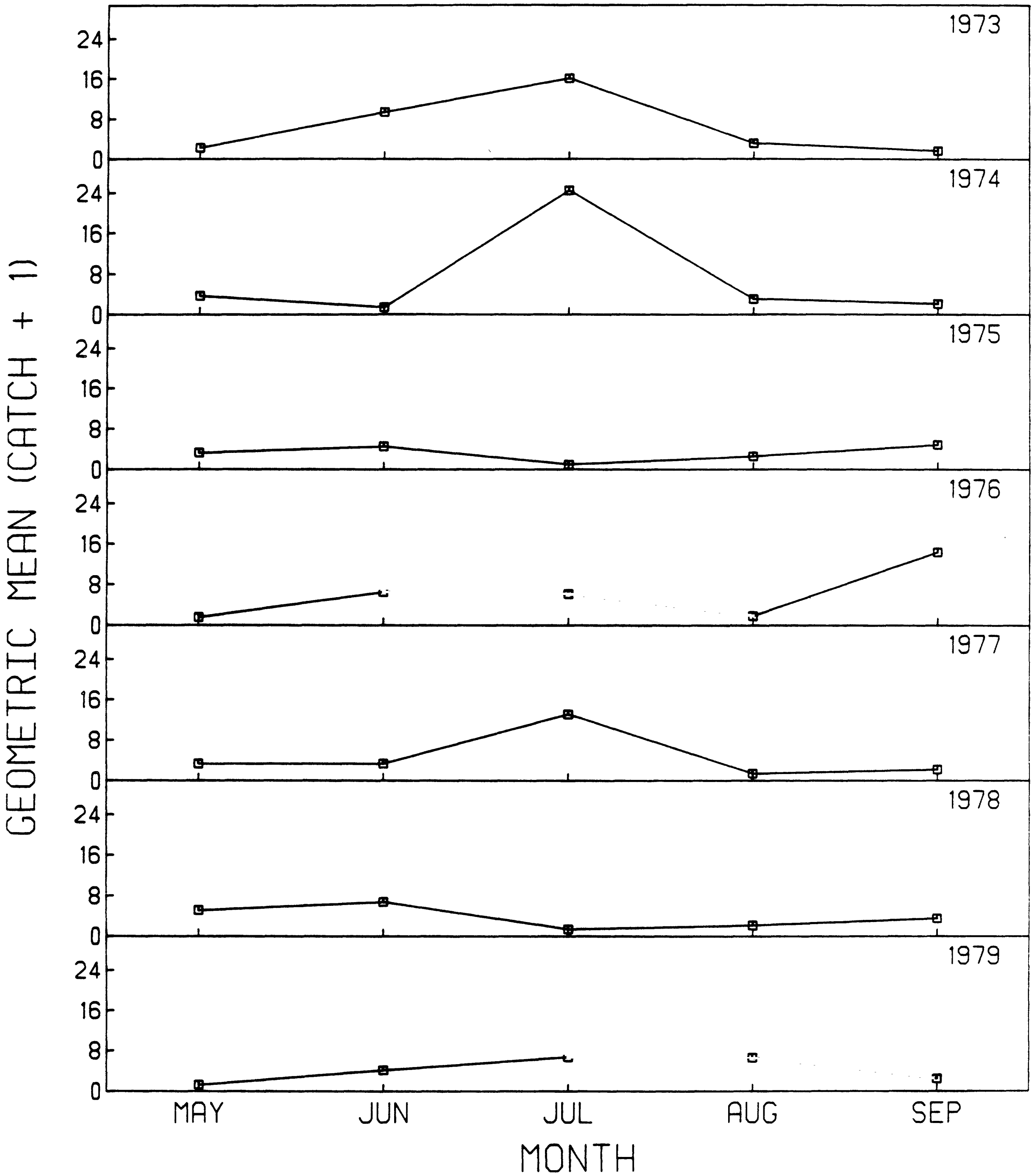


Fig. 52. Monthly geometric mean number of trout-perch caught by standard series gillnetting in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

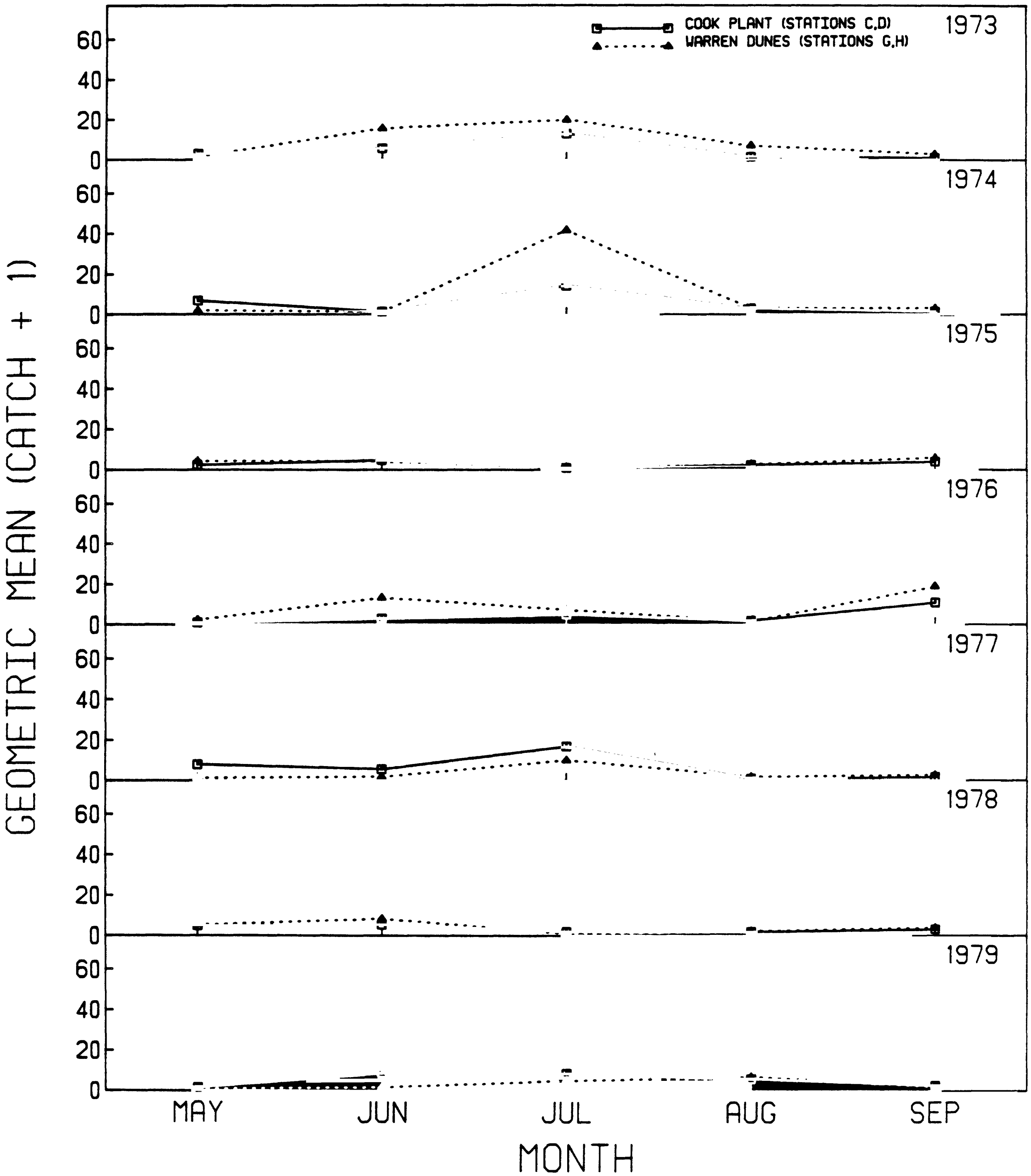


Fig. 53. Monthly geometric mean number of trout-perch caught by standard series gillnetting in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

The addition of stations Q and R in 1975 allowed computation of ANOVA from three areas; north Cook, south Cook, and Warren Dunes. This resulted in the significance of Month, Depth, Area, and the Year x Month interaction (Table 36). The significance of Month and the Year x Month interaction can be explained as in the previous ANOVA, with fluctuating temperatures accounting for much of the variability. The significant Area variable may suggest plant effects. From 1975 to 1979 the south Cook catch was usually largest followed by the Warren Dunes catch; the north Cook catch was smallest (Fig. 54). Using Tukey's test to compare geometric mean catches from the three areas, north Cook catches were found to be significantly smaller than south Cook catches, but not significantly different from Warren Dunes catches at $\alpha = 0.01$. The geometric mean catch at south Cook also did not differ significantly from the Warren Dunes catch. This significant Area effect is apparently due to low trout-perch abundance at north Cook and may be a plant effect. However, no preoperational data from this area are available for comparison. Because trout-perch abundance is also low at Warren Dunes, this pattern of catch could merely reflect the contagious distribution of this species. Hence, low trout-perch abundance at stations Q and R could be due to natural factors.

Seine Data--

Trout-perch were least abundant in seine catches as compared with trawls and gill nets and were more often caught at night than during the day. Night catches from April through October were large enough to analyze by ANOVA.

Years--Analysis of the 1973-1979 seine catch data showed highly significant differences among years (Table 37). Scheffe's test found catches during preoperational years (1973-1974) to be significantly smaller than catches during one-unit (1975-1978) and all operational years (1975-1979). This pattern may

Table 36. Analysis of variance summary for log(catch + 1) of trout-perch. Fish were gillnetted at night from May to September, 1975-1979 in Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df	Mean square	F-statistic	Attained significance level
Year	4	0.1473	2.7717	0.0438
Month	4	0.3760	7.0750	0.0003**
Area	2	0.3149	5.9244	0.0065*
Depth	1	0.6778	12.7546	0.0012*
Y x M	16	0.6679	12.5668	0.0000**
Y x A	8	0.1424	2.6789	0.0224
M x A	8	0.1248	2.3486	0.0412
Y x D	4	0.0541	1.0180	0.4128
M x D	4	0.0271	0.5100	0.7288
A x D	2	0.0187	0.3515	0.7063
Y x M x A	32	0.0908	1.7083	0.0676
Y x M x D	16	0.1052	1.9789	0.0491
Y x A x D	8	0.0990	1.8630	0.1013
M x A x D	8	0.0288	0.5425	0.8156
Y x M x A x D#	32	0.0531		

** Highly significant (P <0.001).
* Significant (P <0.01).
# The Y x M x A x D interaction was assumed to be zero and its mean square was treated as the within cell error mean square.

Table 37. Analysis of variance summary for log(catch + 1) of trout-perch. Fish were seined at night from April to October, 1973-1979 in Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df	Mean square	F-statistic	Attained significance level
Year	6	0.4836	14.2144	0.0000**
Month	6	0.5476	16.0967	0.0000**
Station	2	0.0552	1.6215	0.2011
Y x M	36	0.6328	18.6001	0.0000**
Y x S	12	0.5159	1.5165	0.1241
M x S	12	0.1301	3.8241	0.0000**
Y x M x S	72	0.0921	2.7099	0.0000**
Within cell error	147	0.0340		

** Highly significant (P <0.001).

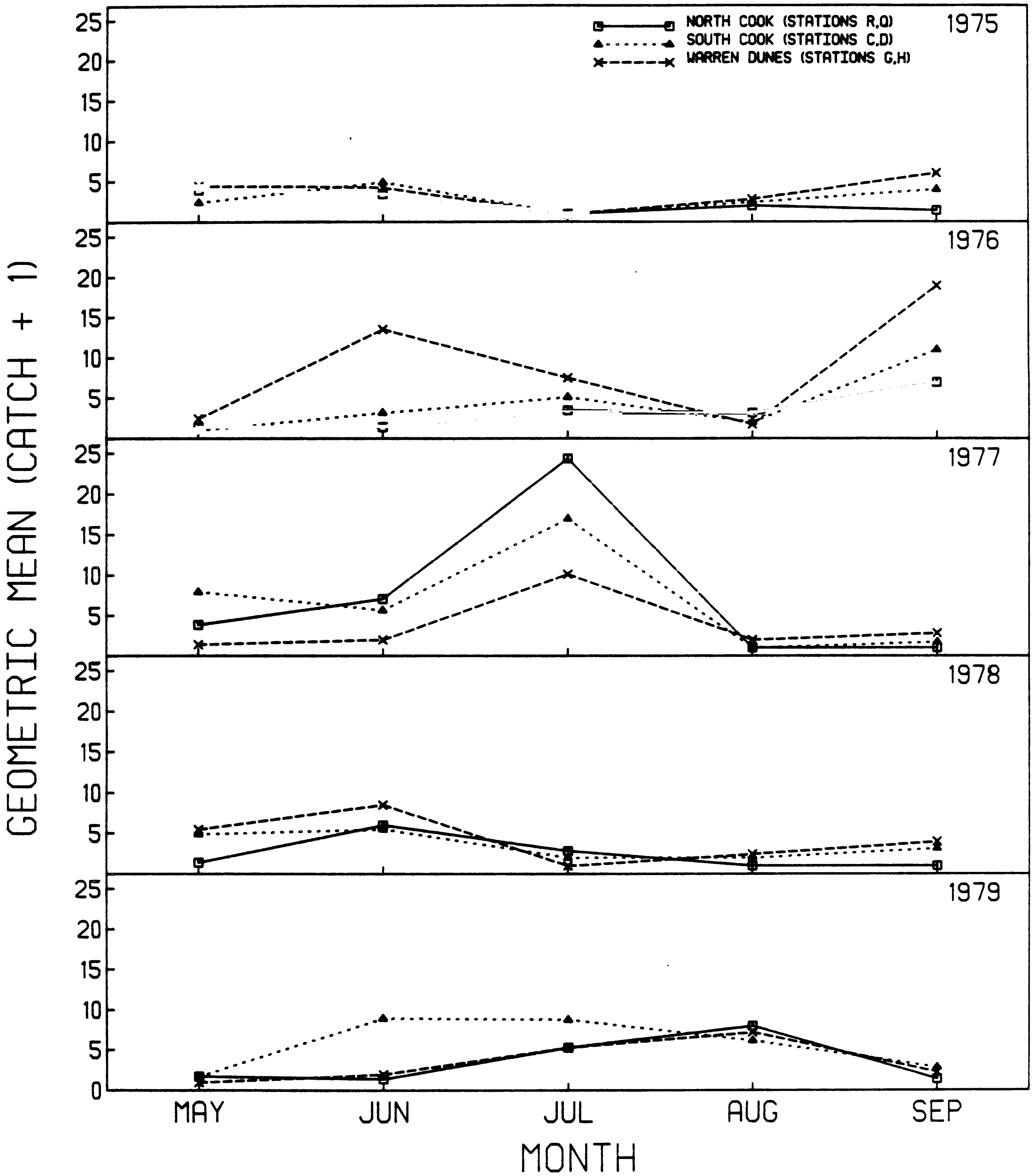


Fig. 54. Monthly geometric mean number of trout-perch caught during operational years 1975-1979 by standard series and stations R and Q gillnetting in Cook Plant study areas, southeastern Lake Michigan.

reflect an effect of plant operation. However, exceptionally small trout-perch catches in 1974 (21 fish) and large catches in 1977 (214 fish) account for much of these differences and no long-term trends were evident (Fig. 55). Trout-perch occupy the beach zone irregularly because their depth distribution is affected by seasonal fluctuating temperatures and upwellings. Therefore, seining data are not a very sensitive indicator of trout-perch abundance. Variable catches from seining are more a reflection of the timing of sampling than an index of abundance.

Areas--There were no significant differences in catch among seining stations. This pattern of catch among stations remained similar over all sampling years as evidenced by the nonsignificant Year x Station interaction. However, the variable Month and the Year x Month interaction were significant. In different years the peak catch occurred during May (1973), June (1977-1979), July (1976), or September (1975, 1977) (Fig. 55). These differences may be due to seasonal temperature differences among years and upwelling changing the distribution of trout-perch in the study area. The significant Month x Station interaction is again probably reflective of the patchy distribution of this species in the lake rather than any effect of plant operation.

Summary of Operational Effects--

Analysis of the trout-perch catch data was complicated by many first- and second-order interactions. In addition, the three sampling methods (trawl, seine, and gill net) were not consistent in indexing trout-perch abundance between years or areas. Much of this variability was probably due to varying vulnerability to the gear, variable year-class strength, patchy distribution, and responses to upwelling and other ambient variables. Comparing catches between preoperational and operational years and between the Cook Plant and

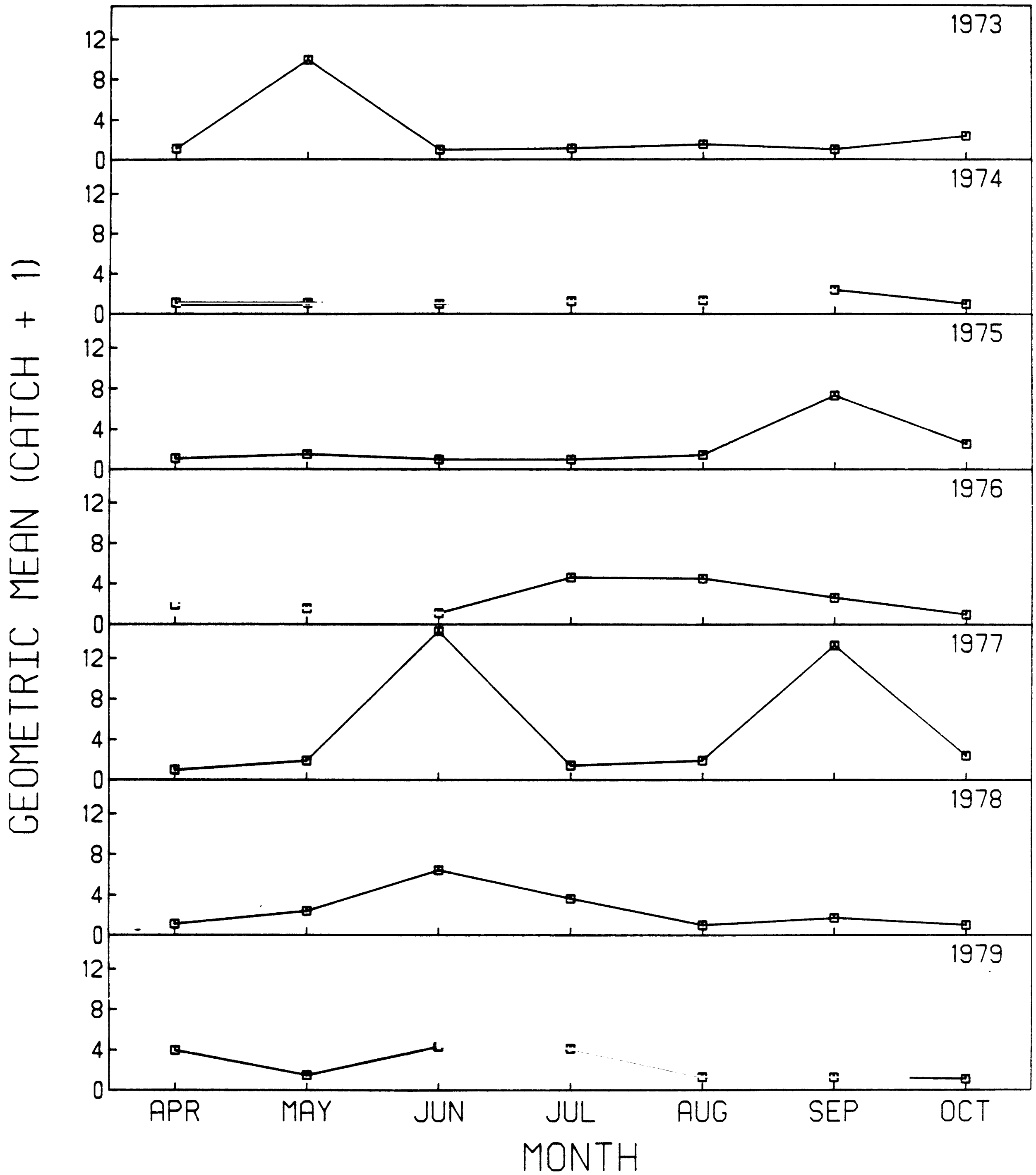


Fig. 55. Monthly geometric mean number of trout-perch caught by standard series seining in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational year and 1975-1979 were operational years.

Warren Dunes areas failed to elucidate any differences in abundance that could be attributed to plant operation.

Distribution and Growth by Age-Group--

Trout-perch age-groups were identified by analysis of length-frequency histograms (Fig. 56). This method allowed identification of three age-groups; young-of-the-year (age 0), yearlings (age 1), and adults (age 2+). Catch of fish from these age-groups fluctuated considerably from 1973 to 1979. However, it was not possible to determine whether these fluctuations were the result of variable year-class strength because young-of-the-year (YOY) were not very susceptible to the gear, and we were not able to distinguish age-groups beyond yearlings. Hence, it was difficult to index the abundance of a cohort through time.

Young-of-the-Year--Trout-perch YOY were caught sporadically by standard series fishing from August through December each year. Individuals first appearing in standard series gear in August or September ranged in mean length from 17 to 33 mm. Mean lengths of individuals caught during October or later were smaller (14-32 mm) than those caught in August or September for a particular year. Small sample sizes may partly account for this anomaly. In addition, the extended spawning season of trout-perch (Table 38) results in younger and smaller individuals becoming susceptible to the gear, depressing the mean length of the cohort. Therefore, determination of growth rates for YOY trout-perch was not possible. The fluctuating mean lengths in each month (Table 39) merely indexed the extended recruitment of YOY into standard series fishing gear.

Yearlings--Yearling growth rates were more discernible from length-frequency histograms. As opposed to YOY, anomalous decreases in mean lengths

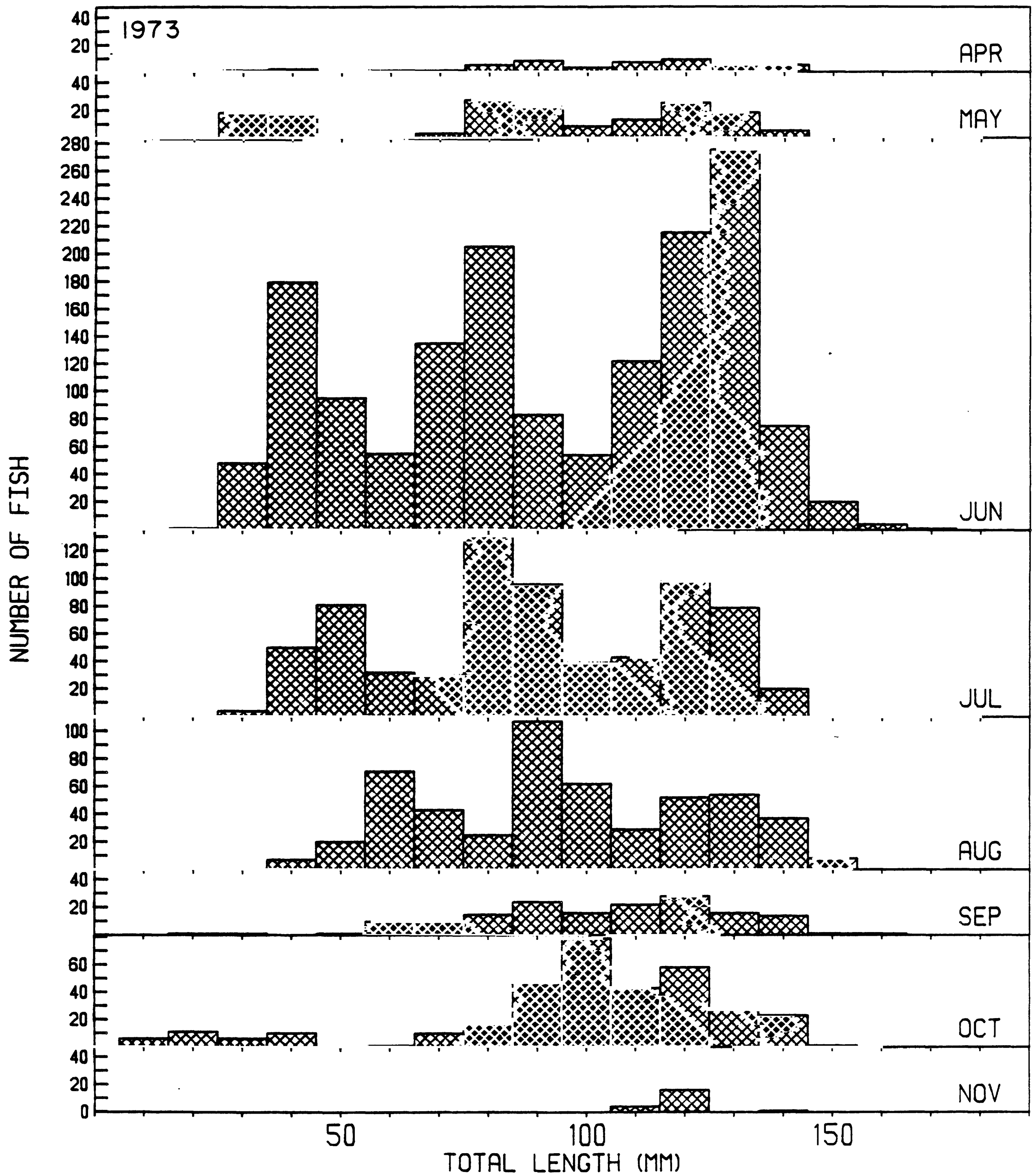
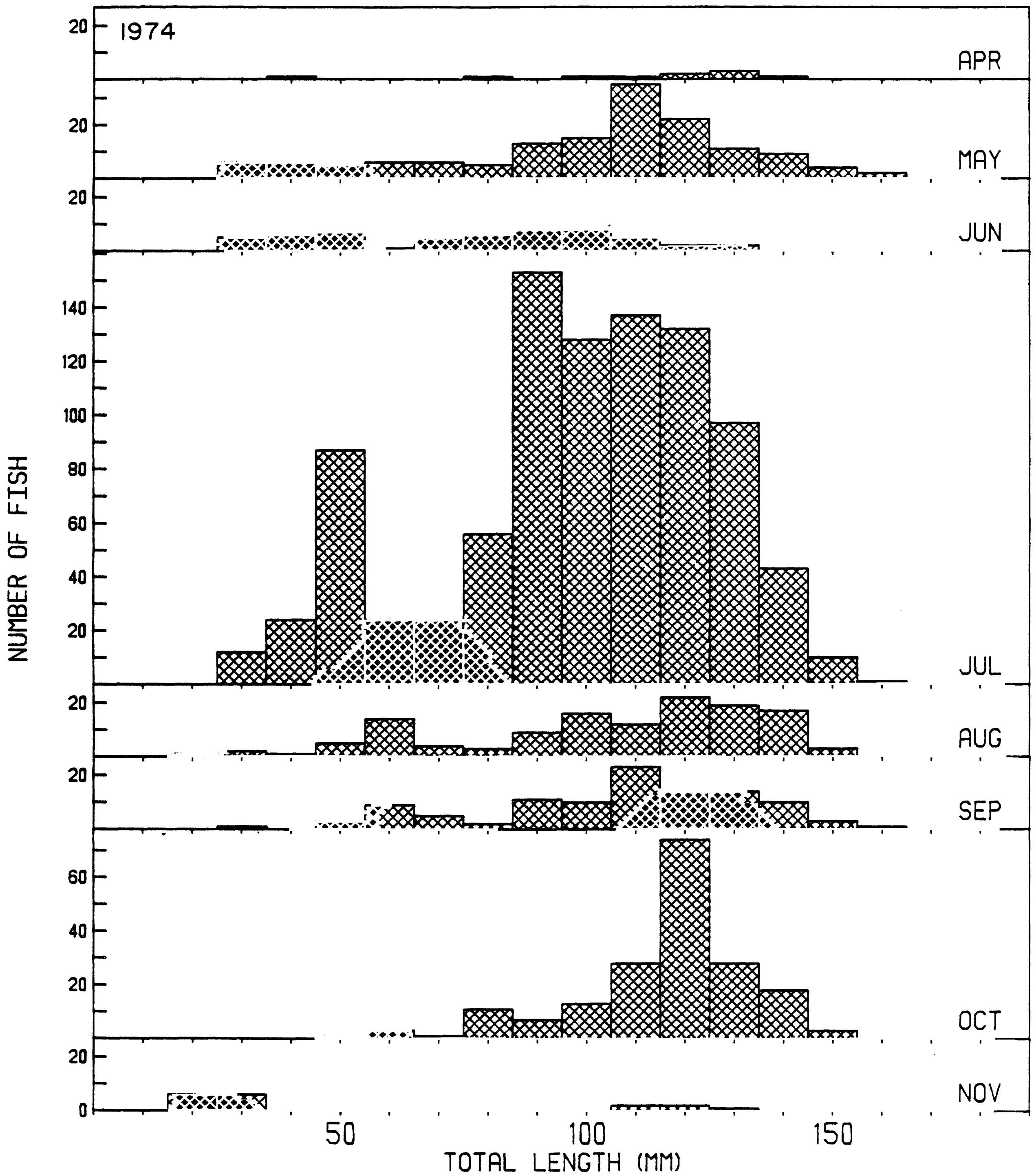


Fig. 56. Monthly length-frequency histograms of trout-perch caught during 1973-1979 by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan.



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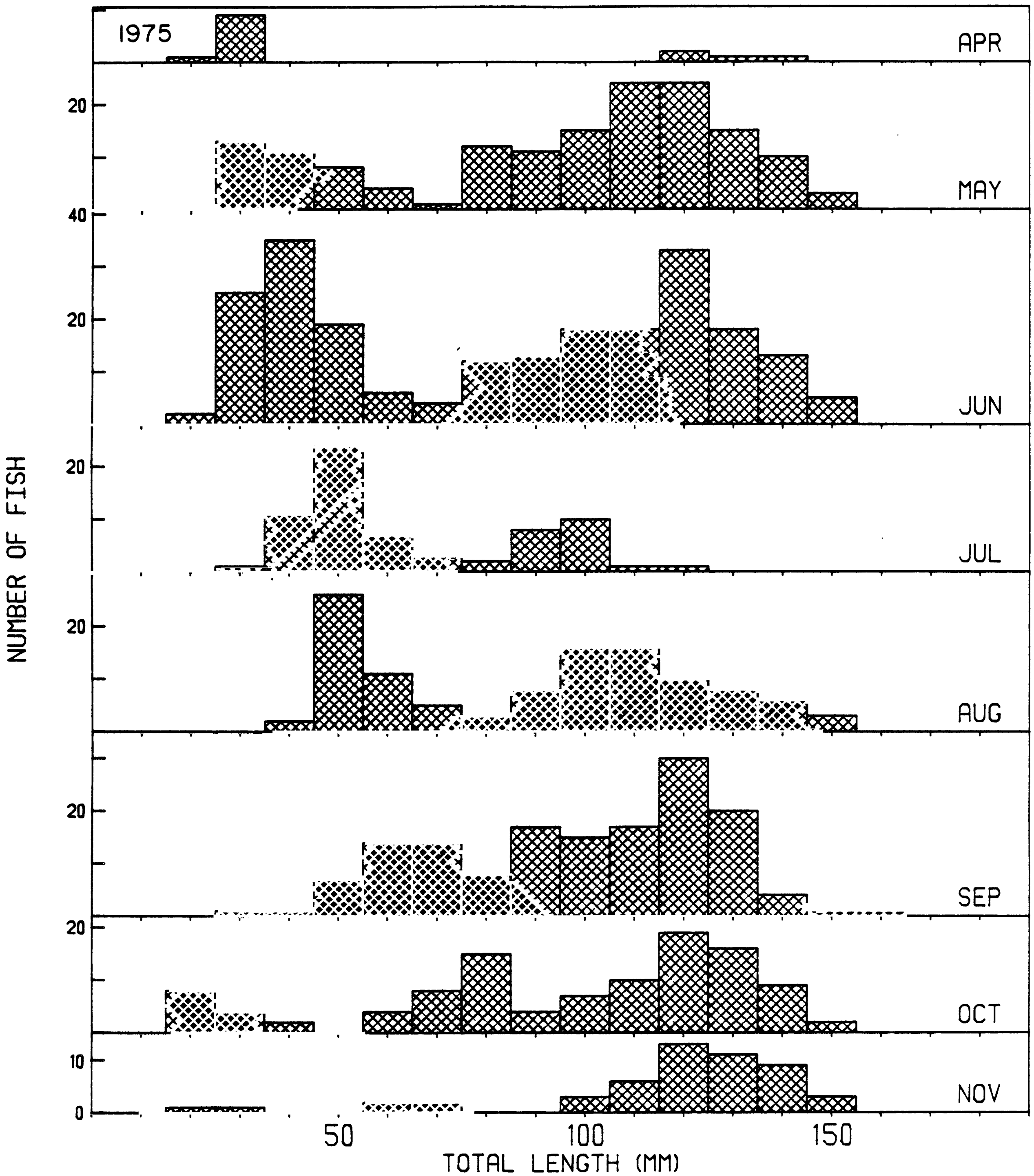

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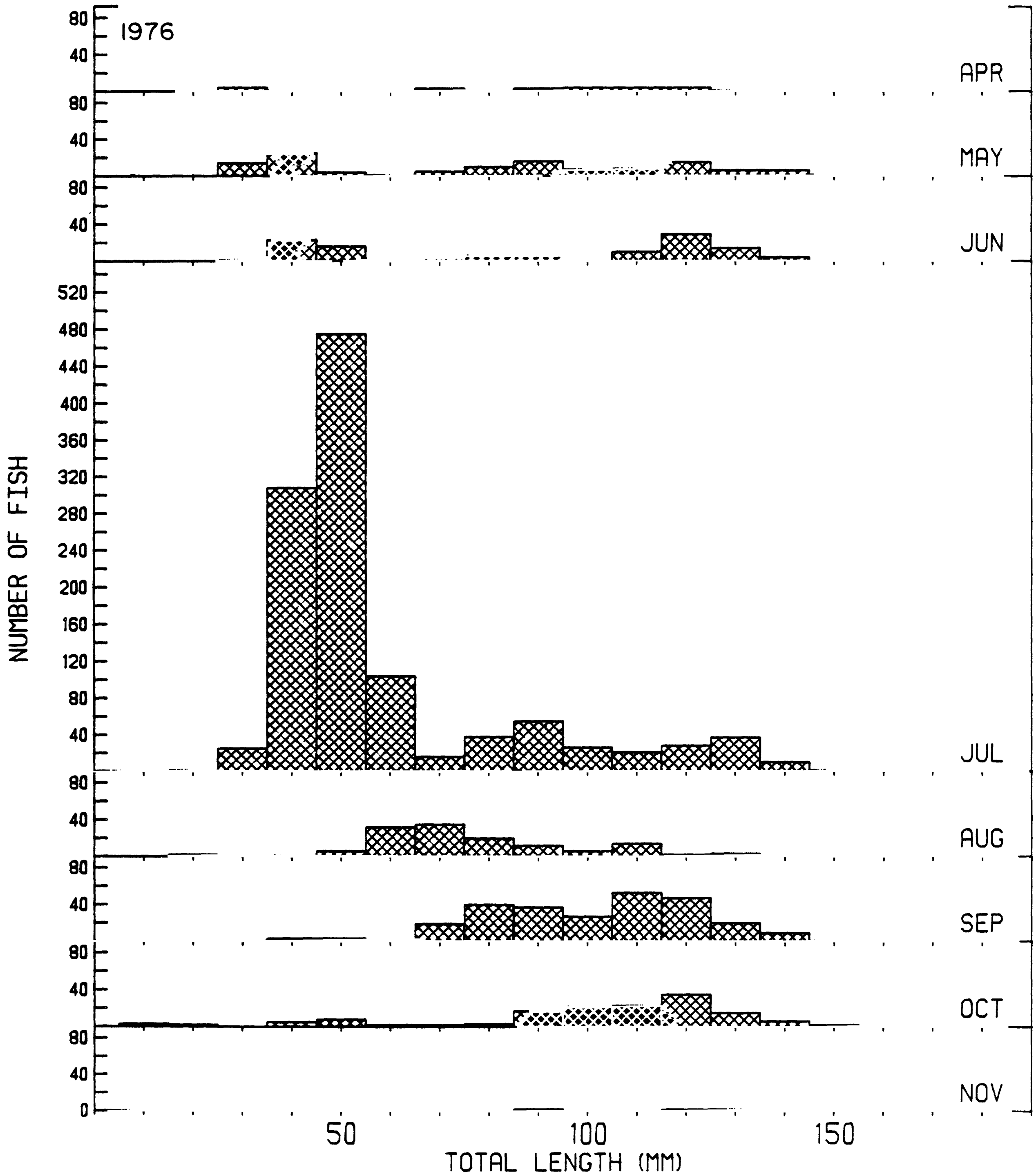

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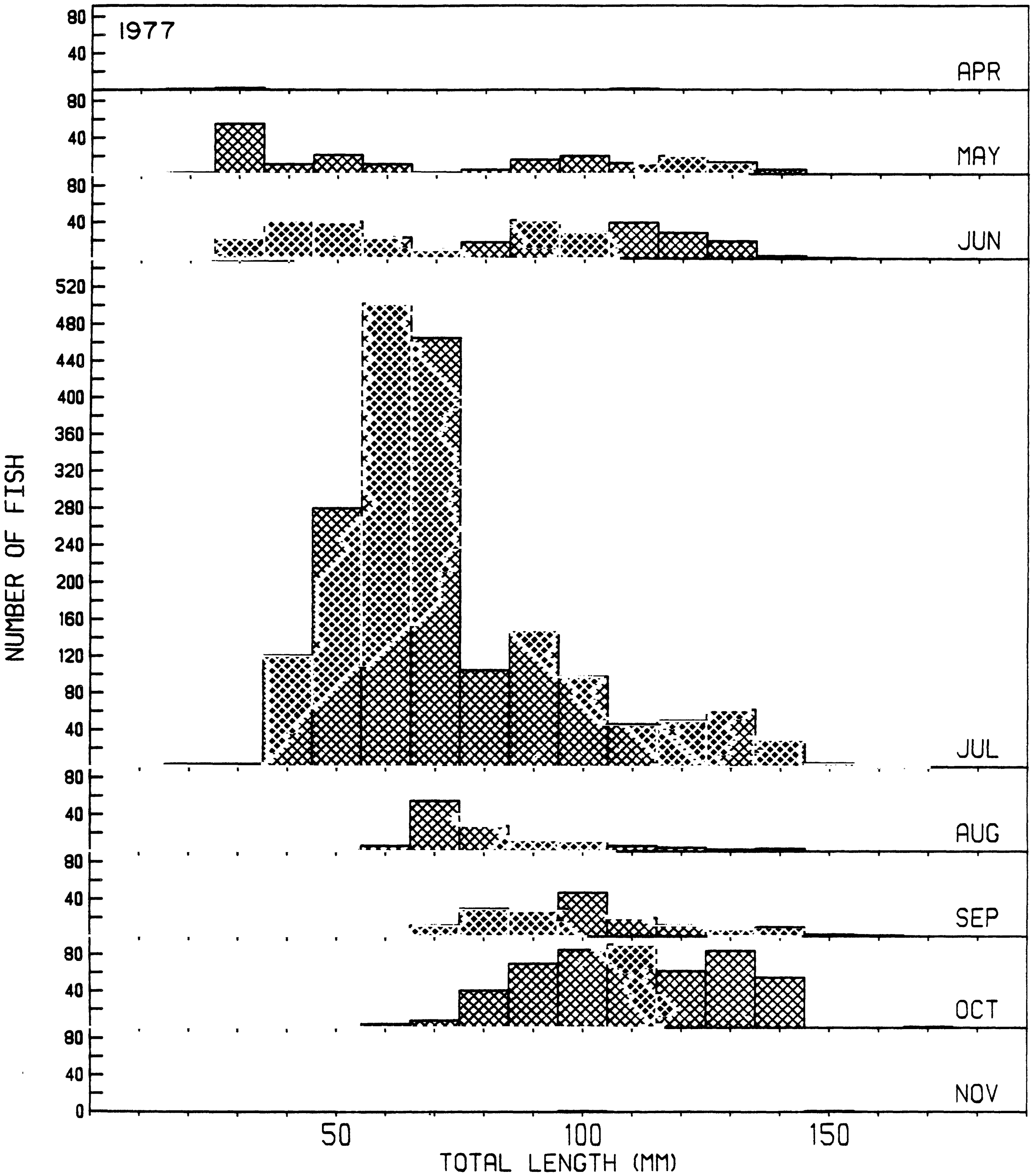

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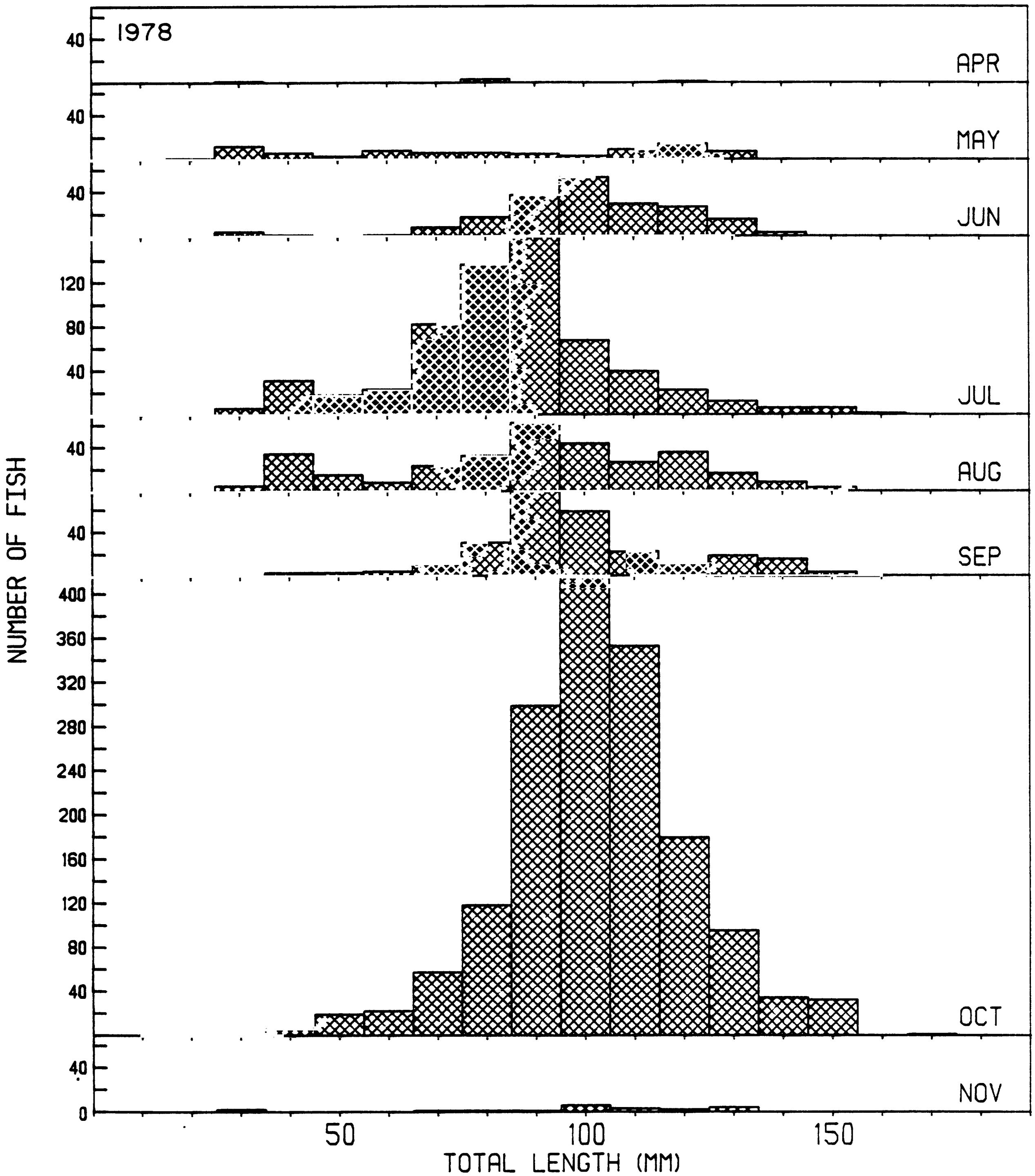

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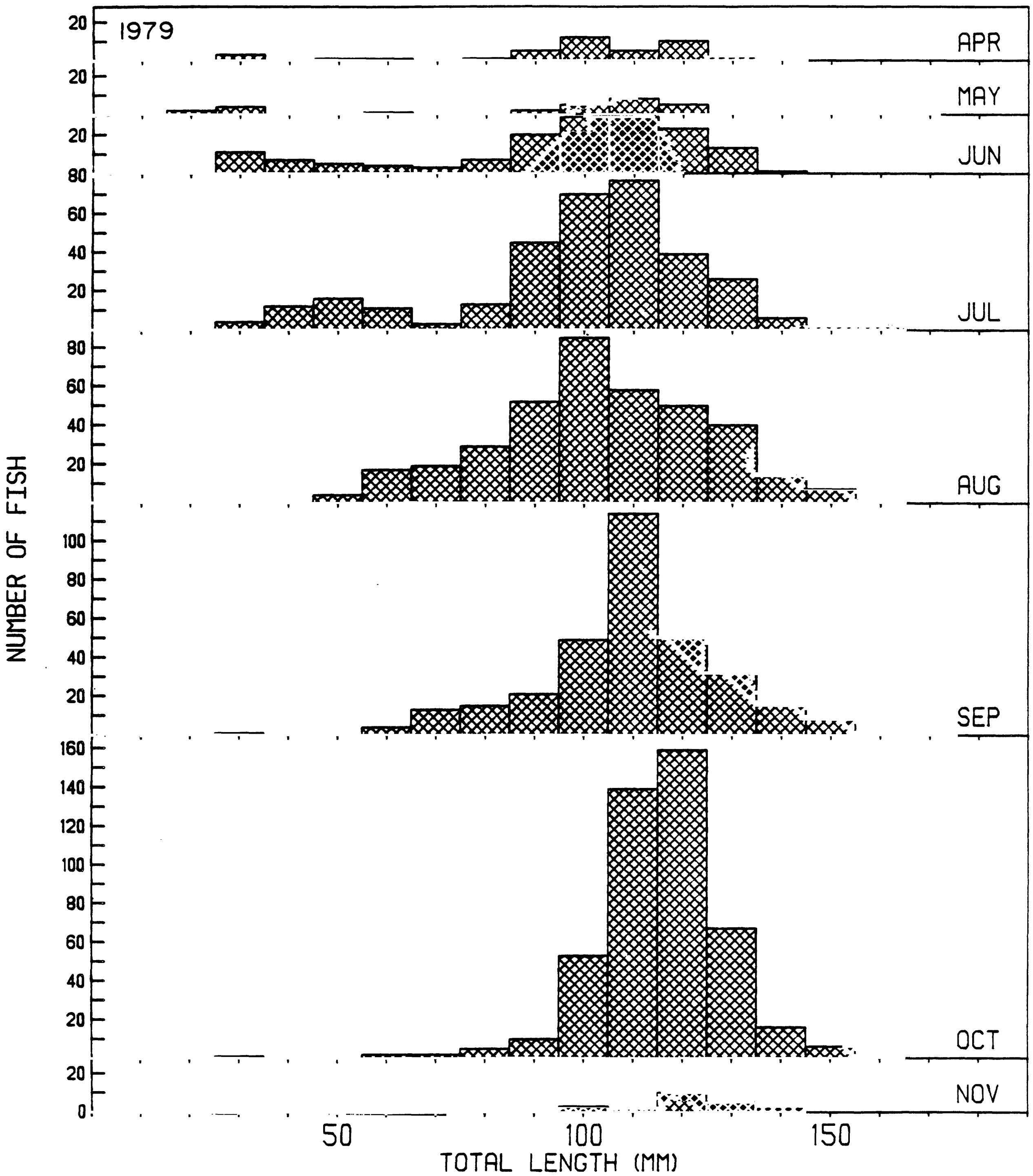


Fig. 56. Continued.

Table 38. Number of ripe and spent trout-perch caught by standard series trawling, gillnetting and seining in Cook Plant study areas, southeastern Lake Michigan, 1973-1979. F = female, M = male, ND = no data.

Year	Sex	Gonad condi-tion	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	F	Ripe	0	18	51	171	100	50	10	1	0	0
		Spent	0	0	3	50	59	68	34	4	1	0
	M	Ripe	0	10	39	93	56	51	6	0	0	0
		Spent	0	1	0	17	33	30	21	0	0	0
1974	F	Ripe	0	4	55	7	123	40	11	2	0	0
		Spent	0	0	4	7	60	21	18	21	0	0
	M	Ripe	0	2	37	10	52	22	6	3	0	0
		Spent	0	0	2	2	13	3	2	5	0	0
1975	F	Ripe	0	1	32	39	3	24	23	0	0	1
		Spent	0	0	2	16	2	13	13	3	0	1
	M	Ripe	0	1	22	26	0	7	2	0	0	1
		Spent	0	0		4	0	2	1	0	0	0
1976	F	Ripe	0	3	7	18	49	8	3	0	1	ND
		Spent	0	3	9	7	30	2	37	3	0	ND
	M	Ripe	0	2	20	13	24	5	0	2	0	ND
		Spent	0	0	0	18	6	0	12	0	0	ND
1977	F	Ripe	0	0	26	46	76	2	7	2	1	0
		Spent	0	0	7	12	61	5	0	0	0	0
	M	Ripe	0	0	34	24	30	1	2	0	0	0
		Spent	0	0	1	0	5	3	0	0	0	0
1978	F	Ripe	ND	1	16	24	68	64	8	12	1	ND
		Spent	ND	0	8	23	29	28	15	3	0	ND
	M	Ripe	ND	0	15	58	73	37	3	5	0	ND
		Spent	ND	0	1	4	3	13	3	0	0	ND
1979	F	Ripe	ND	8	6	19	69	48	3	0	0	ND
		Spent	ND	0	0	2	30	18	1	0	0	ND
	M	Ripe	ND	11	2	8	29	29	0	1	0	ND
		Spent	ND	0	0	1	4	8	0	0	0	ND

Table 39. Mean length in mm ±SD of trout-perch young-of-the-year and yearlings caught by standard series netting in Cook Plant study areas, southeastern Lake Michigan, 1973-1979. Sample size is given in parentheses.

	Year class							
Month	1972	1973	1974	1975	1976	1977	1978	1979
				Young-of-the-year				
Aug			25 ±9 (3)		18 ±1 (2)		33 ±1 (5)	
Sep		26 ±6 (2)	32 (1)	33 (1)				33 (1)
Oct		25 ±11 (34)		24 ±6 (14)	15 ±4 (5)		32 ±7 (10)	32 ±2 (2)
Nov			25 ±6 (12)	25 ±3 (2)			29 ±4 (2)	
Dec				28 ±4 (5)				
				Yearlings				
Apr	36 ±3 (3)	39 (1)	26 ±2 (11)	33 ±6 (6)	26 ±5 (3)	25 (1)	29 ±2 (3)	
May	34 ±4 (35)	39 ±8 (17)	40 ±10 (37)	38 ±6 (48)	30 ±4 (74)	35 ±9 (22)	29 ±6 (13)	
Jun	43 ±9 (151)	41 ±9 (18)	39 ±8 (133)	43 ±6 (34)	40 ±8 (73)	33 ±27 (5)	36 ±6 (24)	
Jul	65 ±20 (244)	46 ±8 (85)	49 ±8 (49)	47 ±8 (341)	45 ±8 (167)	41 ±6 (65)	48 ±9 (55)	
Aug	74 ±16 (209)	58 ±7 (23)	55 ±10 (52)	65 ±8 (117)	65 ±5 (23)	44 ±7 (68)	60 ±6 (35)	
Sep	70 ±9 (36)	61 ±8 (18)	65 ±11 (50)	78 ±13 (116)	73 ±6 (46)	51 ±8 (11)	69 ±9 (30)	
Oct	83 ±9 (48)	74 ±10 (16)	73 ±9 (37)	73 ±20 (47)	74 ±8 (54)	61 ±10 (110)	71 ±9 (11)	
Nov			66 ±12 (8)	89 ±4 (3)		73 (1)		
Dec			81 ±8 (3)					

were not detected for yearlings (Fig. 57). It appeared appropriate to assume that growth compensation occurred during their first year resulting in trout-perch tending to some average mode as yearlings. Therefore, we treated all age-1 individuals as a cohort experiencing a similiar growth pattern.

Mean lengths of April-caught yearlings ranged from 25 to 39 mm. Relative monthly growth rates (Everhart et al. 1975) were usually greatest from June to July, ranging from 0.09 in 1976 to 0.51 in 1973. However, the greatest absolute increase in growth usually occurred from July to August at rates of 0.44 to 0.70 mm/day. Growth generally remained rapid from spring through fall. In addition, as opposed to rainbow smelt, no correlation was found between trout-perch growth and abundance.

Adults--Adult trout-perch (age 2+) were regularly caught by standard series fishing gear. The modal lengths of April-caught adults ranged from 80 to 120 mm (Fig. 56). Since age-1 individuals attained lengths of 61 to 83 mm by October, most trout-perch that were the modal length in the age 2+ group were undoubtedly age-2. In addition, most trout-perch were apparently mature by age-2, because 90% of all trout-perch which attained a length of 80 mm were mature and most yearlings in the fall were already approaching this length. Length at maturity was similar in preoperational and operational year.

These data fail to show any plant effects on trout-perch growth. Although growth rates fluctuated among years, no long-term trends were apparent. In addition, length at maturity did not change with plant operation. Hence, variables other than plant operation appear to be affecting trout-perch growth in the study areas.

Temperature-catch relationships--

Trout-perch temperature preferences have been described only generally.

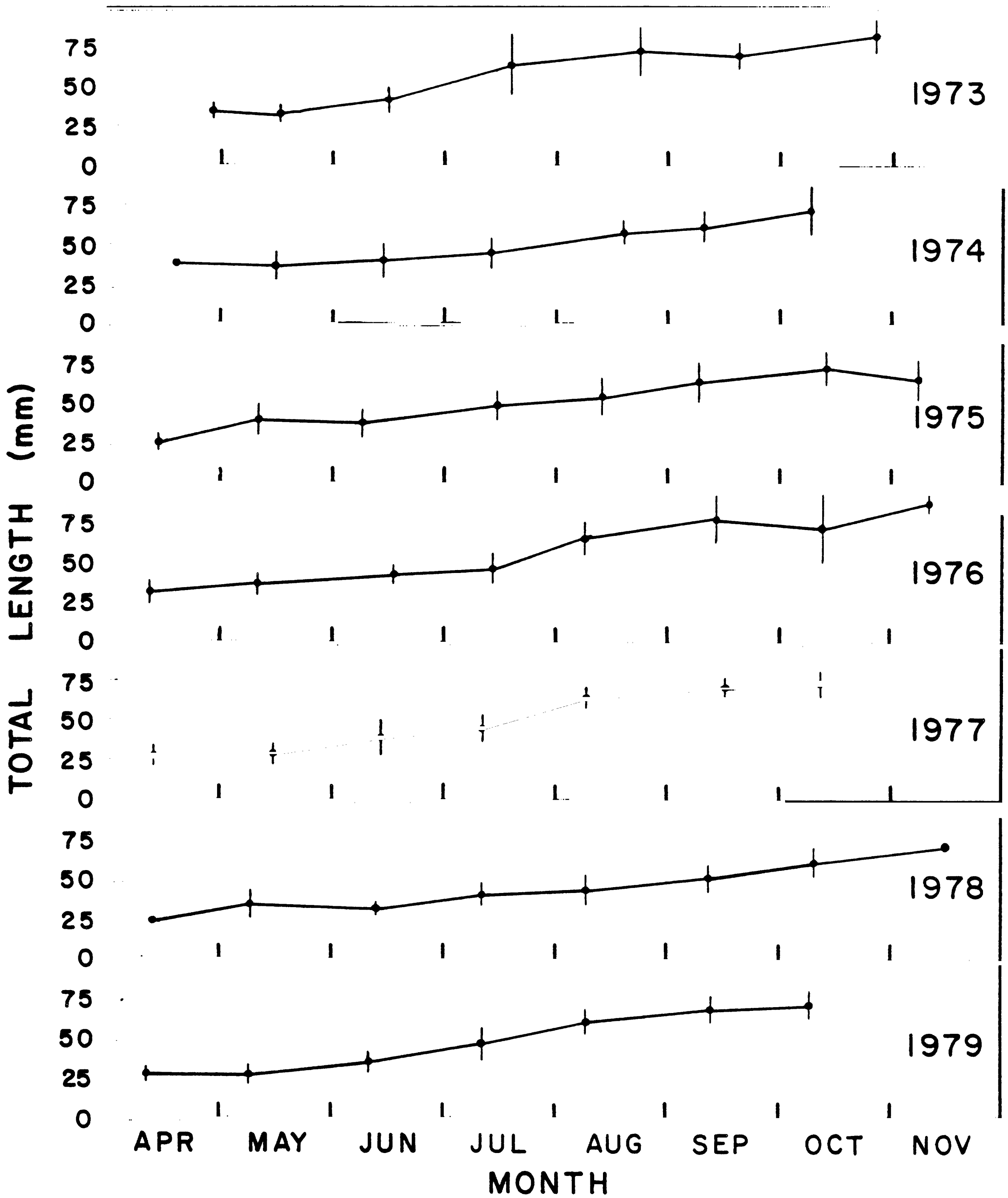


Fig. 57. Mean total length ($\pm$ one standard deviation) of yearling trout-perch caught during 1973-1979 by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan.

Wells (1968) caught trout-perch in Lake Michigan primarily in waters from 10 to 16°C. However, Dryer (1966) found trout-perch in the Apostle Islands region of Lake Superior to be widely distributed down to a depth of 90 m and hence inhabiting much cooler waters. Brandt et al. (1980) caught trout-perch over a narrow temperature range during the day (15-16°C) but found them to occupy a wider range of temperatures at night. Much remains to be learned about the temperature preferences of trout-perch.

In this study, trout-perch were caught most frequently in temperatures from 14.6 to 20.5°C (Fig. 58). Outside this range of temperatures, trout-perch were more often caught in cooler than warmer waters. However, considerably more fishing effort occurred in cooler waters. Therefore, this distribution of catch by temperature does not necessarily suggest a preference for cooler waters.

The characteristic diel inshore-offshore movement patterns of this species also confuses analysis of temperature selection. Diel differences in depth selection, and hence temperature selection, may also account for the bimodal peak catches in Figure 58. At night, trout-perch make shoreward movements which bring them into warmer waters than they inhabit during the day. Emery (1973) also observed trout-perch in Lake Huron to reside at or below the thermocline during the day and move into warmer, shallower waters at night.

All age-size groups of trout-perch apparently had similar temperature preferences (Fig. 59). This is in contrast to other abundant species caught in the Cook Plant vicinity, including alewife, rainbow smelt, spottail shiner, and yellow perch. The young-of-the-year of those species were caught at warmer temperatures than older fish. The slightly reduced mean temperatures observed for trout-perch less than 35 mm is apparently because YOY were not large enough to be vulnerable to standard series fishing until fall when temperatures were usually below what is preferred by all other sizes of trout-perch.

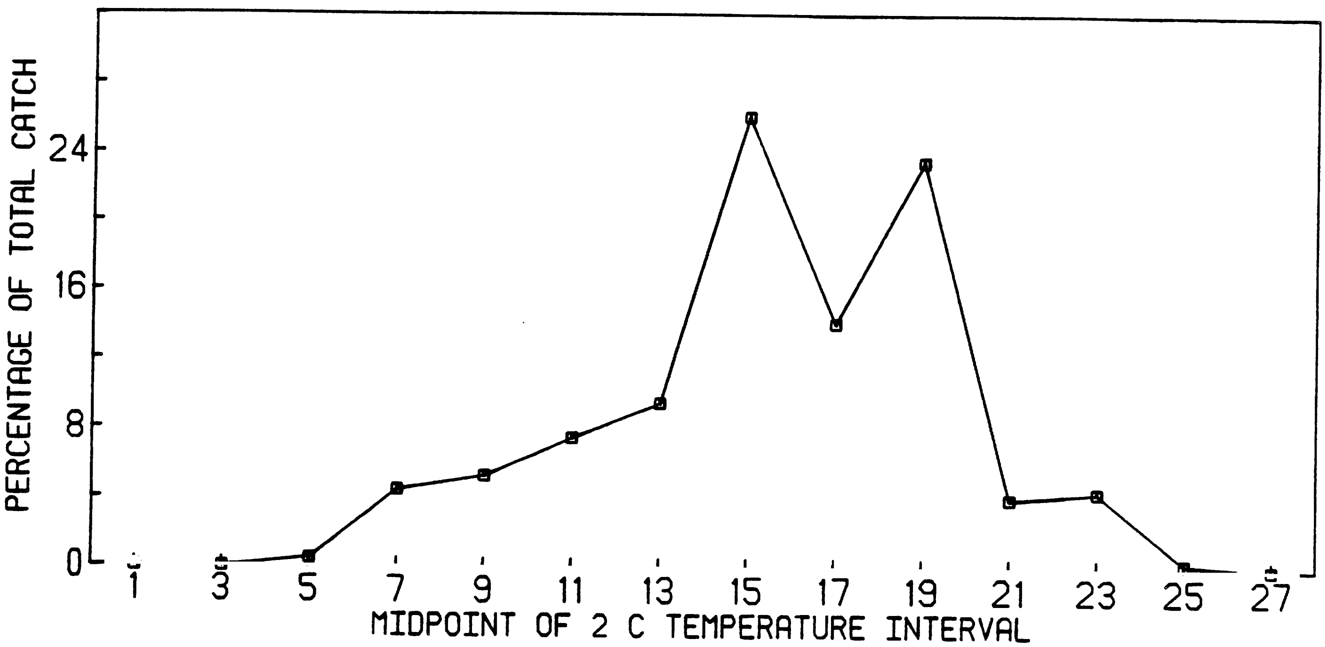


Fig. 58. Percentage of the combined total standard series catch of trout-perch collected during 1973-1979 from various temperatures in Cook Plant study areas, southeastern Lake Michigan.

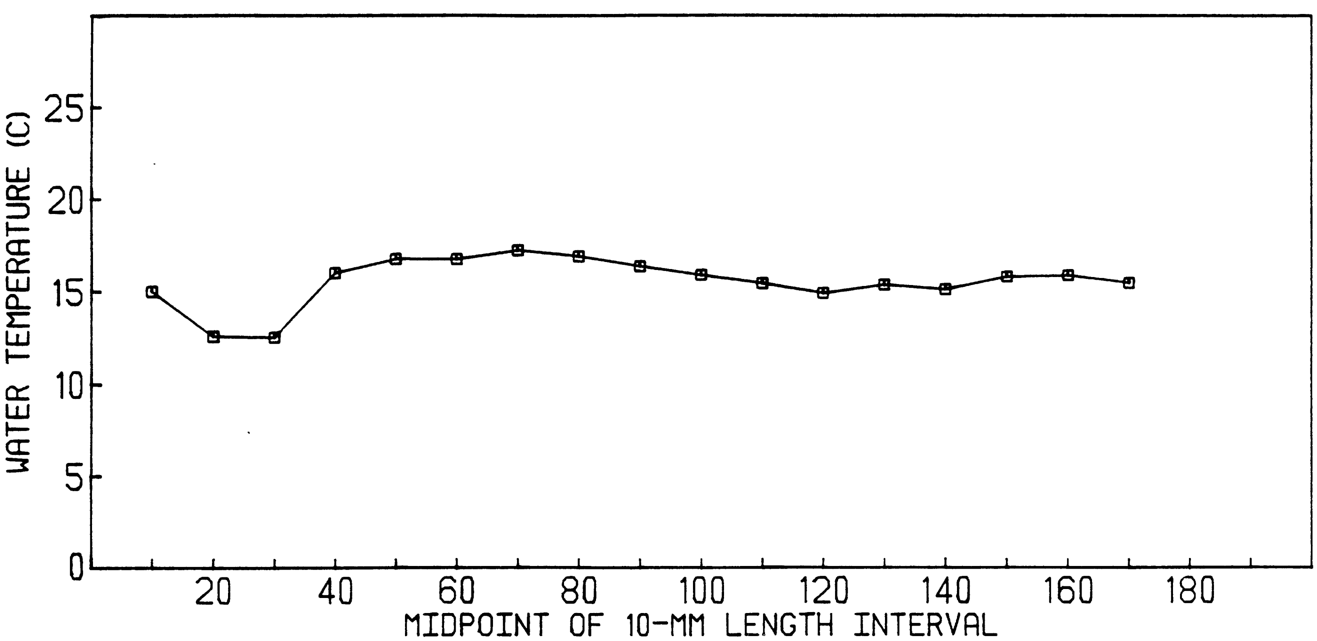


Fig. 59. Mean temperature at which various sizes of trout-perch were caught during 1973-1979 by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan.

Other Considerations--

Nocturnal activity and inshore-offshore movements have been described for trout-perch by several investigators. Emery (1973) observed trout-perch by scuba in Georgian Bay and Algonquin Park, Ontario, and found them to make shoreward movements at night. He also classified them as dusk and nighttime feeders. Magnuson and Smith (1963), using seines and trawls, found essentially similar behavior of trout-perch in Minnesota's Red Lakes. They observed diel inshore migrations at night followed by a retreat to deep, offshore water during the day. Other aspects of trout-perch activity and distribution remain poorly understood.

Jude et al. (1979) found trout-perch near the Cook plant during preoperational years to exhibit diel behaviors like those described for other areas. In addition, they suggested that disruption of these behaviors during operational years may suggest evidence of plant effects. Data collected during operational years were examined for such changes. Long-term data also were examined for other more poorly understood aspects of these behaviors.

Trout-perch were more frequently caught at night than during the day by standard series fishing. Overall, 69% of the trout-perch catch in gill nets, trawls, and seines occurred at night. These increased catches at night suggest that trout-perch are nocturnally active. Hence, our catch data from standard series fishing support previous descriptions of trout-perch diel activity.

Examination of stomach contents provides another criterion for defining periods of activity in fishes. Although netting data indicate nocturnal activity for trout-perch, a slightly higher percentage of trout-perch stomachs contained food during the day. This occurred with all gear types and over a range of temperatures. Because netting data indicated nocturnal activity,

greater percentages of full stomachs obtained from the day catch was unexpected. Slow digestive rates may account for these differences between times of peak catch and stomach fullness. In addition, Swift (1964) points out that periods of peak feeding are not necessarily synonymous with peak activity in fishes. In this case, nocturnal activity may be more associated with inshore-offshore movements to and from feeding and resting areas than the feeding forays. Greater percentages of trout-perch were caught at beach stations at night than during the day (Fig. 60). These catch differences may be, in part, the result of trout-perch avoiding the seine during the day. However, inshore-offshore movements undoubtedly are also a factor.

The pattern of the day-night catch differed with temperature (Fig. 61). In warmer waters trout-perch were caught more selectively at night. This may be due to trout-perch restricting their activities to night as the lake warms in summer. During spring and fall when temperatures are low, trout-perch may be more active during the day. However, we believe this may also be the result of differences in the magnitude of inshore-offshore movements with temperature. As inshore areas sampled by our gear warm above 20°C, trout-perch reside farther offshore in deeper, cooler areas during the day. Under these conditions, inshore movements into the sampled depths at night result in the greatest disparity between day and night catches. As inshore waters cool and the lake becomes more nearly isothermal, trout-perch are less able to select an area of preferred temperature for daytime inactivity by making inshore or offshore movements. Hence, the day-night catch ratio becomes less pronounced. This hypothesis for temperature affecting inshore-offshore movements agrees well with a study by Brandt et al. (1980) who found trout-perch to be more stenothermal during the day than night. Therefore, when the lake is stratified, diel inshore-offshore movements should be more pronounced than when the lake is isothermal.

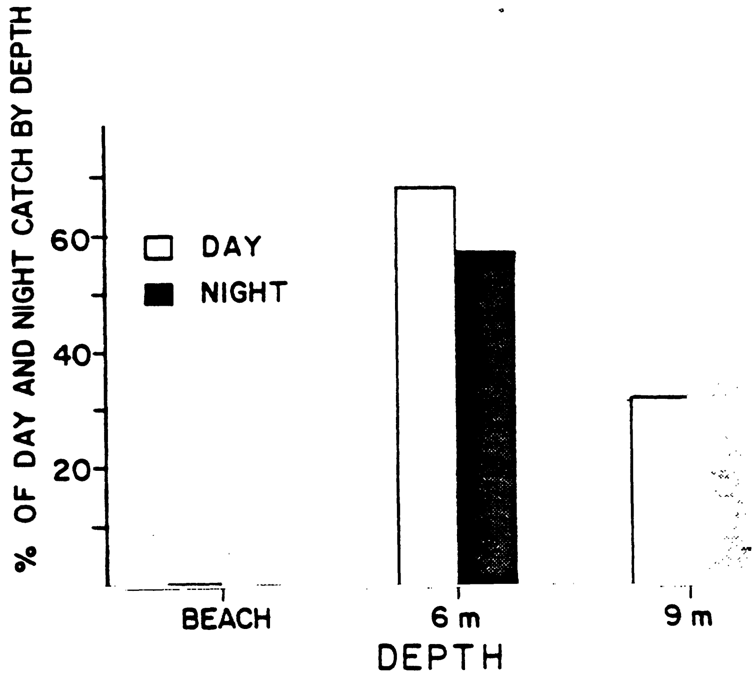


Fig. 60. Percentage of the trout-perch catch from 1, 6, and 9-m depths collected during the day and during the night in Cook Plant study areas, southeastern Lake Michigan.

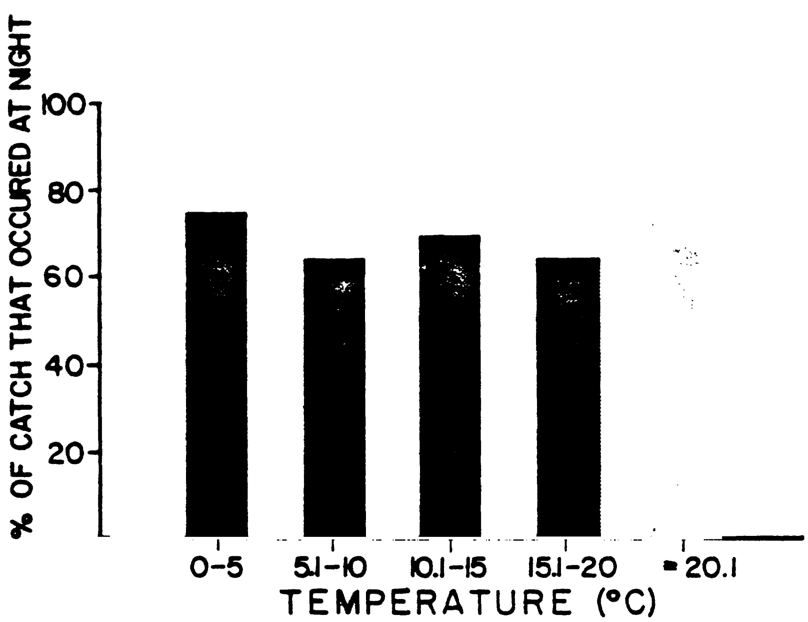


Fig. 61. Percentage of trout-perch during 1973-1979 collected at night from various temperatures in the Cook Plant study areas, southeastern Lake Michigan.

These behaviors did not appear to be affected by plant operation. Nocturnal activity and shoreward movements were similar during preoperational and operational years. In addition, although diel activity and inshore-offshore movements appeared to be temperature related, these behaviors appeared unchanged during operational years at Cook Plant study areas.

Yellow Perch

Introduction--

Yellow perch inhabit all of the Great Lakes and are abundant in shallow areas such as Green Bay, the southern part of Lake Michigan, Saginaw Bay, Lake St. Clair, and the western basin of Lake Erie. Although perch have been abundant in the shallow areas of Lake Michigan since at least the 1800s (Wells and McLain 1973), the populations have fluctuated in recent years. In the early and mid 1960s, perch populations probably declined as a result of the alewife preying on perch larvae, and the intensive fisheries for perch (Wells 1977). Perch populations have increased in some areas of Lake Michigan in the 1970s, although a full recovery appears unlikely as long as the alewife is abundant (Wells 1977).

Yellow perch has been an important part of the fisheries of Lake Michigan. Salmonines and coregonines have been the most valued and sought-after commercial fishes; but whenever their populations declined, yellow perch became a heavily exploited species in parts of the lake (Smith 1972, Wells and McLain 1973). Commercial catch of yellow perch averaged 1.1 million kg from 1889 to 1970, which was usually less than 10% of the lake's total commercial production (Wells and McLain 1973). While salmonines have been the most

important sport fishes in the past decade, yellow perch was the most important sport species in previous years (Wells and McLain 1973).

In southeastern Lake Michigan, yellow perch display seasonal and diel movements. During mid fall and winter, perch are at depths from 9 to 37 m (Wells 1968, 1977; Jude et al. 1979, 1981). In late April and early May, adults begin moving shoreward to spawn (Wells 1968, 1977; Brazo et al. 1975). From late May to early June, adults aggregate and spawn over rough bottoms at 5-13 m (Wells 1977, Dorr 1982). During summer, all age-groups of perch are at depths from 13 m to shore (Wells 1968, Jude et al. 1979). Yellow perch are day-active and nocturnally inactive, with presunset and postsunrise activity peaks (Helfman 1979) during summer and fall; perch move toward shore at sunset and away from shore at sunrise (Emery 1973, Willis 1975, Jude et al. 1979). These seasonal and diel inshore movements cause yellow perch to be susceptible to impingement and plume effects at the Cook Plant.

Analyses of preoperational catch data revealed considerable variation in perch abundance and distribution (Jude et al. 1979). Much of this catch variation was attributable to seasonal population movements, diel activity changes, population age-structure changes, and meteorological (especially temperature) influences. An attraction to the plant's riprap, which was present in preoperational study years, may have been another influence on perch distribution. In general, though, no substantial differences were found in the distribution or abundance of perch between the two study areas.

From 1973 and 1979, yellow perch was a seasonally abundant species in the study areas. Standard series catches ranged from 1,576 fish in 1978 to 4,659 in 1979 and averaged 3,531 fish. Although perch were collected year-round in the study areas, 91% were caught from June to September. Perch catches by

gear type were similar for the 7 years; average catches for seines, trawls, and gill nets were, respectively, 1,354, 1,097, and 1,070 fish.

Trawl Data--

Trawl catches varied from 2,598 fish in 1979 to 313 fish in 1974. Trawls captured most sizes of perch, except for larvae and fish over 345 mm. ANOVA was applied to catch data from June to October; catches in other months were too small for statistical analyses.

Years--ANOVA showed geometric mean catches among years were significantly different (Table 40). Scheffe's test further revealed that the 1973 catch was significantly larger than the other years' mean catch, as was the catch in 1979; mean catch in 1974 was significantly smaller. The overall small catch in 1974 resulted from small catches during all months, while in 1973 catches were generally large during all months (Fig. 62). Large catches in August and especially September 1979 caused that year's mean catch to be significantly greater than the mean catch for the other years. Because fluctuations occurred within preoperational and operational years, the significant differences in yearly catches were not related to plant operation. Further evidence for this conclusion is that Scheffe's test found the catch in preoperational years was not significantly different from the operational years' catch.

Areas--Mean catches between areas were not significantly different (Table 40). Also, the Year x Area interaction was not significant. Monthly changes in area catches were generally similar within the same year (Fig. 63). These findings add further evidence that sampling by trawls did not establish any changes in yellow perch abundance which could be attributed to plant operation during 1975 through 1979.

Table 40. Analysis of variance summary for log(catch + 1) of yellow perch. Fish were trawled from June to October, 1973-1979 in Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df#	Adjusted mean square##	F-statistic	Attained significance
Year	6	4.0716	38.1754	0.0000**
Month	4	6.3990	59.9971	0.0000**
Area	1	0.1871	1.7541	0.1865
Depth	1	0.0991	0.9294	0.3359
Time	1	6.5437	61.3539	0.0000**
Y x M	24	2.0669	19.3790	0.0000**
Y x A	6	0.2649	2.4835	0.0234
M x A	4	0.1272	1.1927	0.3142
Y x D	6	0.3385	3.1735	0.0050*
M x D	4	1.0447	9.7953	0.0000**
A x D	1	0.0071	0.0669	0.7961
Y x T	6	0.3943	3.6973	0.0015*
M x T	4	0.9740	9.1323	0.0000**
A x T	1	0.1975	1.8516	0.1747
D x T	1	0.0003	0.0028	0.9580
Y x M x A	24	0.2108	1.9761	0.0051*
Y x M x D	24	0.3816	3.5775	0.0000**
Y x A x D	6	0.1027	0.9628	0.4507
M x A x D	4	0.0551	0.5169	0.7234
Y x M x T	24	0.6870	6.4411	0.0000**
Y x A x T	6	0.1686	1.5806	0.1527
M x A x T	4	0.1119	1.0492	0.3822
Y x D x T	6	0.2150	2.0157	0.0637
M x D x T	4	0.4164	3.9040	0.0042*
A x D x T	1	0.0643	0.6028	0.4382
Y x M x A x D	24	0.1671	1.5666	0.0475
Y x M x A x T	24	0.1757	1.6473	0.0315
Y x M x D x T	24	0.2693	2.5253	0.0002**
Y x A x D x T	6	0.1445	1.3544	0.2332
M x A x D x T	4	0.1350	1.2653	0.2838
Y x M x A x D x T	24	0.0968	0.9078	0.5915
Within cell error	279	0.1067		

\# One degree of freedom was subtracted from the error term to correct for a missing observation where the cell mean was substituted.

\## Mean squares were multiplied by harmonic mean cell size/maximum cell size (nh/n = 0.9975) to correct for one missing observation where cell mean was substituted.

** Highly significant (P <0.001).

* Significant (P <0.01).

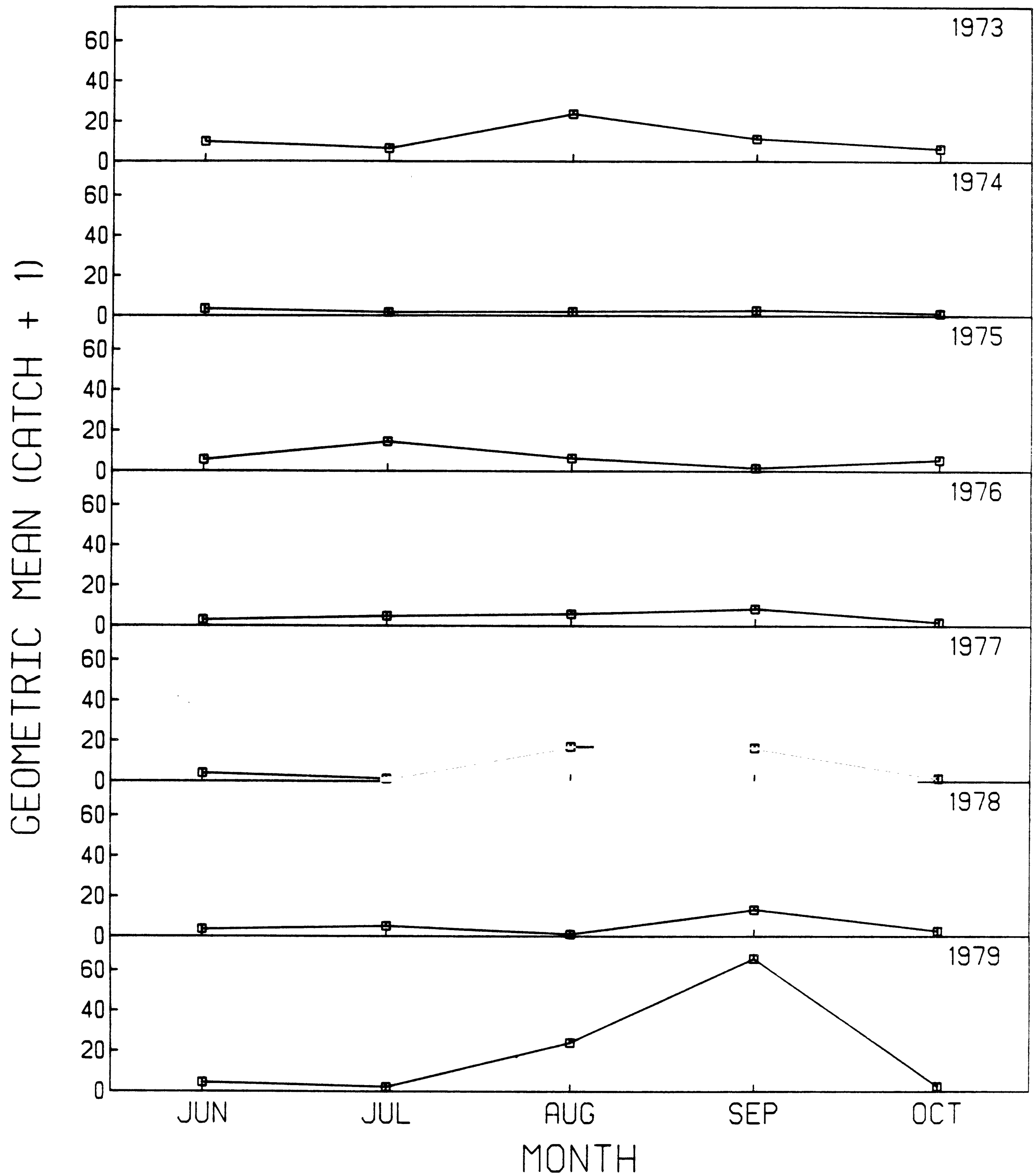


Fig. 62. Monthly geometric mean number of yellow perch caught by standard series trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

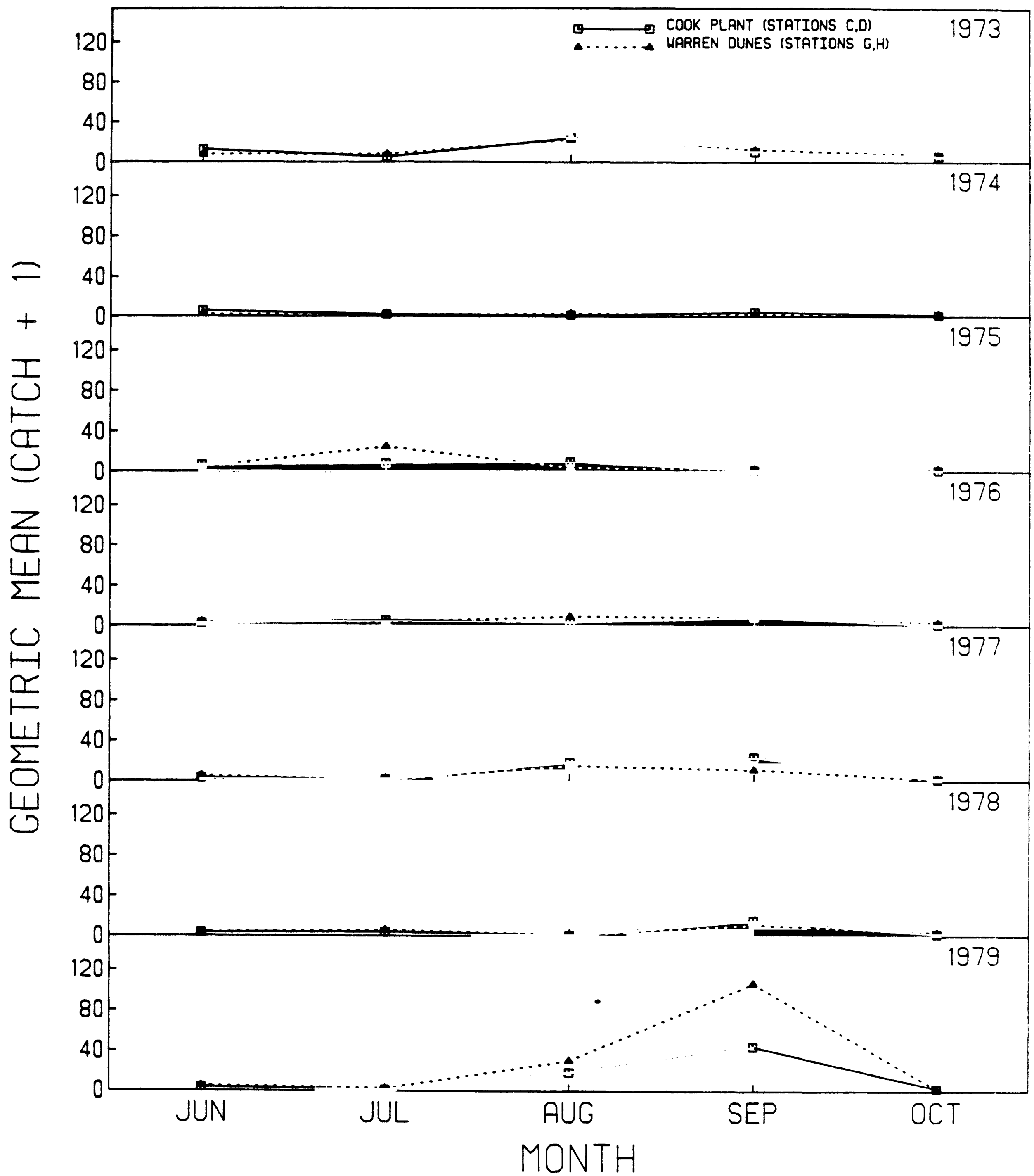


Fig. 63. Monthly geometric mean number of yellow perch caught by standard series trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

To further analyze for plant effects, trawl catch data from 1975 to 1979, with the addition of the north Cook 6-m station R, were subjected to ANOVA. Year and Station catches were significantly different; however, the Year x Station interaction was not significant (Table 41). Scheffe's test showed again, like the 1973-1979 analysis, that mean catch in 1979 was significantly different from the other years' mean catch. Significant differences among station catches resulted from disparity between the largest mean catch, which occurred at the 9-m Warren Dunes station, and the smallest mean catch, which occurred at station R. But Scheffe's test revealed that mean catch at the Warren Dunes 6-m station was not significantly different from the mean catch at the Cook Plant 6-m stations; also, the mean catch at both Warren Dunes trawl stations was not significantly different from the mean catch at the three Cook Plant stations. Catches at the Warren Dunes 6-m station tended to be greater than at the Cook Plant 6-m stations (Fig. 64), however these differences were not great enough to cause significant differences between stations. These findings, like the analysis of 1973-1979 trawl data without station R catches, demonstrated no variation which could be attributed to plant operation.

Gill Net Data--

Annual gill net catches ranged from 740 perch in 1978 to 1,442 fish in 1973. Only catches from June to October were large enough and consistent enough to analyze statistically.

Years--Monthly gill net catches showed no pattern among years; generally, catches were larger in August and September than in June and July (Fig. 65). However, yearly mean gill net catches were statistically different (Table 42). Scheffe's test showed mean catches in 1974 and 1978 were significantly smaller

Table 41. Analysis of variance summary for log(catch + 1) of yellow perch. Fish were trawled from June through October, 1975-1979 in Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df	Mean square	F-statistic	Attained significance
Year	4	1.5169	15.2515	0.0000**
Month	4	7.3535	73.9369	0.0000**
Station	4	0.4104	4.1269	0.0030*
Time	1	11.7058	117.6984	0.0000**
Y x M	16	3.0947	31.1166	0.0000**
Y x S	16	0.1893	1.9033	0.0206
M x S	16	0.2951	2.9675	0.0002**
Y x T	4	0.3164	3.1810	0.0142
M x T	4	0.2589	2.6029	0.0366
S x T	4	0.1465	1.4731	0.2109
Y x M x S	64	0.2491	2.5046	0.0000**
Y x M x T	16	0.5316	5.3451	0.0000**
Y x S x T	16	0.1791	1.8008	0.0314
M x S x T	16	0.2303	2.3157	0.0034*
Y x M x S x T	64	0.1913	1.9234	0.0002**
Within cell error	250	0.0995		

** Highly significant (P <0.001).
* Significant (P <0.01).

than the other years' mean catch, while the 1975 mean catch was significantly larger. Because no trend occurred between preoperational and operational years and significantly small catches occurred during both periods, these changes could not be ascribed to plant effects.

<u>Areas</u>--Mean catches between areas were significantly different with larger catches at the Cook Plant; however, the Year x Area interaction was not significant. Yellow perch catches were greater at the Cook Plant during both preoperational and operational years (Fig. 66). The magnitude of this

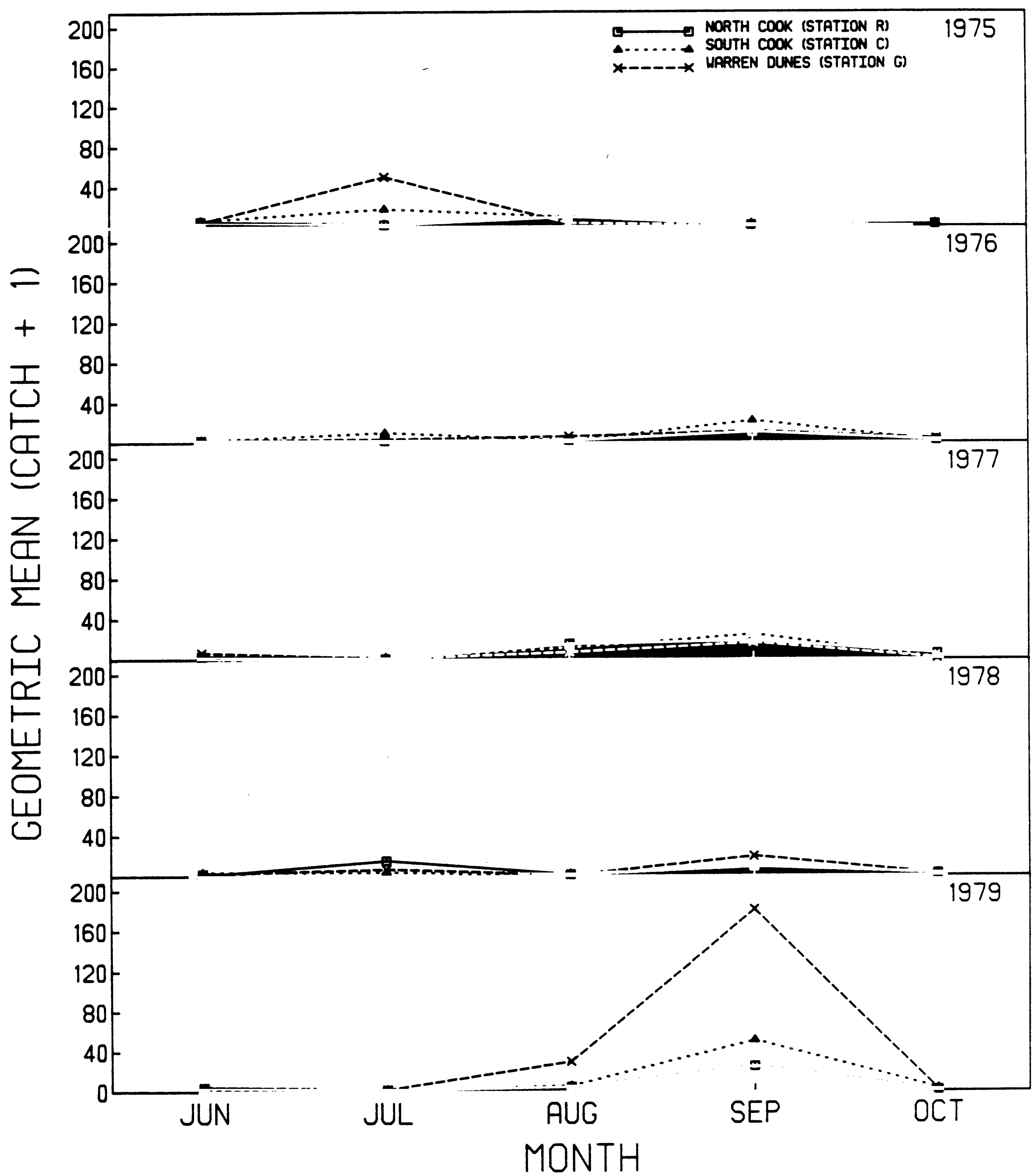


Fig. 64. Monthly geometric mean number of yellow perch caught during operational years 1975-1979 by standard series and station R trawling in Cook Plant study areas, southeastern Lake Michigan.

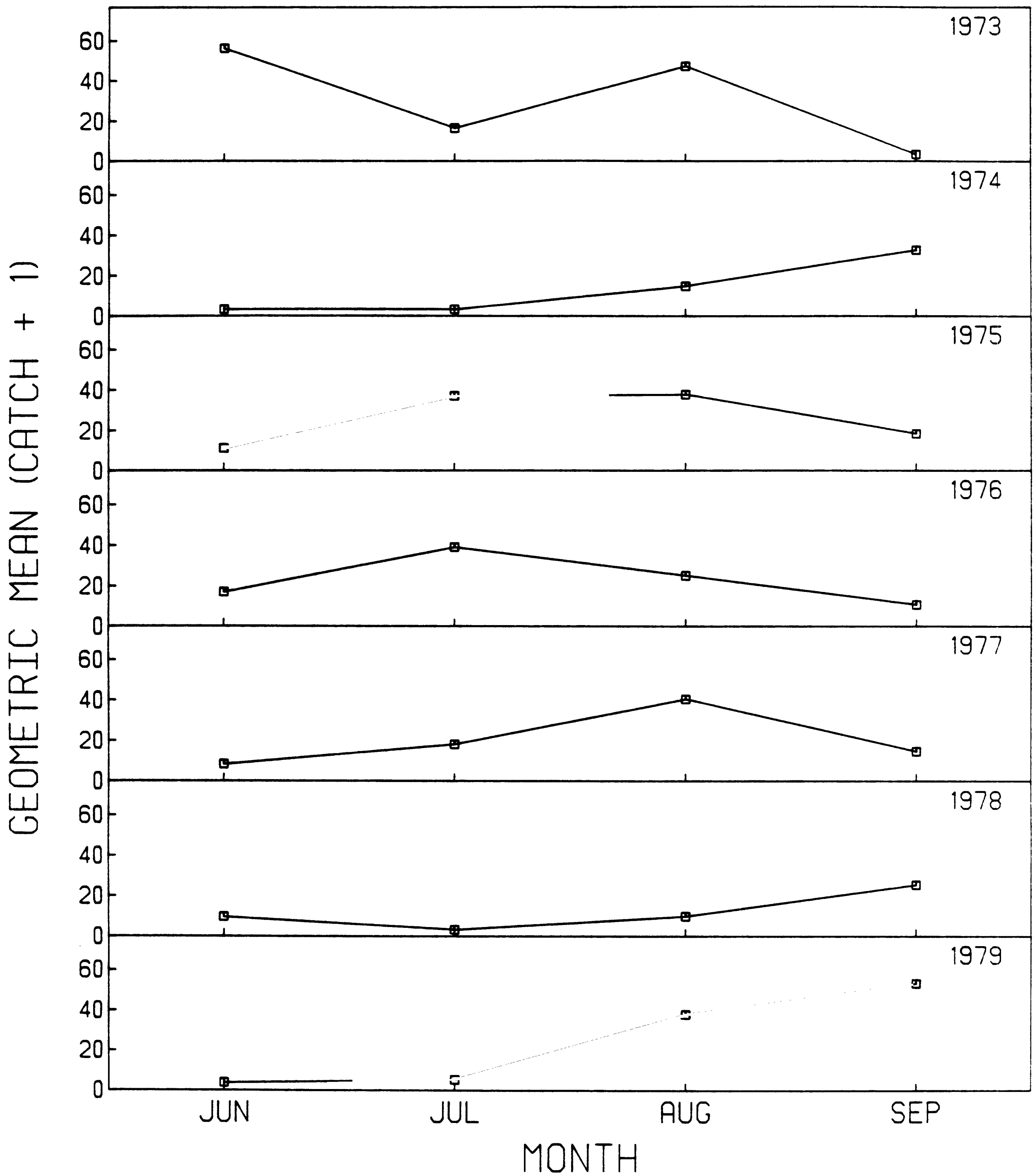


Fig. 65. Monthly geometric mean number of yellow perch caught by standard series gillnetting in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

Table 42. Analysis of variance summary for log(catch + 1) of yellow perch. Fish were gillnetted from June to September, 1973-1979 in Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df	Mean square	F-statistic	Attained significance
Year	6	0.9101	12.8644	0.0000**
Month	3	2.0465	28.9273	0.0000**
Area	1	0.6639	9.3848	0.0067*
Depth	1	0.0136	0.1923	0.6662
Time	1	0.2497	3.5300	0.0766
Y x M	18	1.2956	18.3131	0.0000**
Y x A	6	0.0680	0.9610	0.4783
M x A	3	0.0640	0.9041	0.4585
Y x D	6	0.3406	4.8142	0.0043*
M x D	3	1.3954	19.7240	0.0000**
A x D	1	0.0078	0.1105	0.7435
Y x T	6	0.6912	9.7702	0.0001**
M x T	3	0.2870	4.0575	0.0229
A x T	1	0.0218	0.3088	0.5853
D x T	1	0.9798	13.8509	0.0016*
Y x M x A	18	0.1755	2.4808	0.0307
Y x M x D	18	0.4054	5.7297	0.0003**
Y x A x D	6	0.0632	0.8929	0.5207
M x A x D	3	0.0417	0.5888	0.6302
Y x M x T	18	0.4194	5.9283	0.0002**
Y x A x T	6	0.0463	0.6553	0.6859
M x A x T	3	0.1306	1.8463	0.1750
Y x D x T	6	0.0922	1.30026	0.3058
M x D x T	3	0.1538	2.1740	0.1265
A x D x T	1	0.0143	0.2023	0.6582
Y x M x A x D	18	0.0579	0.8188	0.6620
Y x M x A x T	18	0.1296	1.8330	0.1041
Y x M x D x T	18	0.1431	2.0228	0.0723
Y x A x D x T	6	0.1493	2.1099	0.1027
M x A x D x T	3	0.0820	1.1597	0.3524
Y x M x A x D x T#	18	0.0707		

** Highly significant (P <0.001).
* Significant (P <0.01).
# The Y x M x A x D x T interaction is assumed to be zero and its mean square is treated as the within cell error mean square.

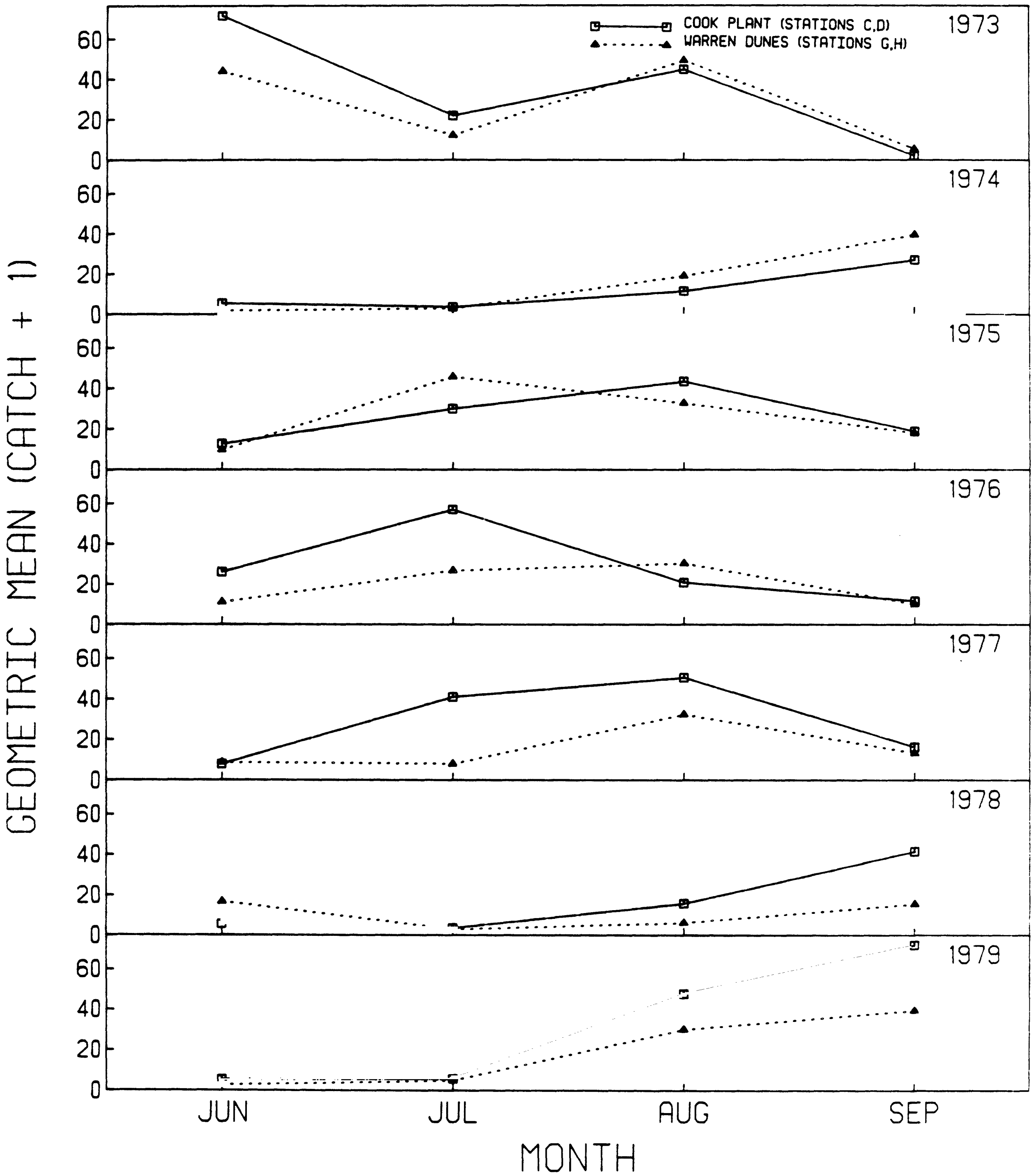


Fig. 66. Monthly geometric mean number of yellow perch caught by standard series gillnetting in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

difference has increased in operational years of the study. Greater abundance at the plant area may be caused by the power plant. Yellow perch are attracted to rocky or rough substrates in Lake Michigan (Wells 1977, Dorr 1982), including the Cook Plant's riprap (Dorr and Jude 1980, Dorr 1982). Also, yellow perch during summer are attracted to thermal discharges in Lake Ontario (Storr and Schlenker 1974), and the discharges at the Cook Plant are probably an added attraction to the Cook Plant area. During summer, perch fishermen in small boats frequently congregate off the plant's discharges, apparently successfully catching yellow perch. Storr and Schlenker (1974) attributed the attraction of perch to thermal discharges to protection from wave activity and to an increase in food from the heated water attracting prey. We can add that currents from the Cook Plant's high velocity discharges and prey organisms, either dislodged by currents or entrained through the plant, may also be attractants.

While gill net data indicated an attraction of perch to the Cook area, trawl and seine data did not confirm this finding. This contradiction could be the result of gear selectivity. Gill nets effectively sampled large adult perch while the other two types of gear did not. Larger perch may be attracted while smaller, younger fish are not.

Gill net catch data from 1975 to 1979 were further analyzed for plant effects by the addition of catch data from north Cook 6- and 9-m stations R and Q. This allowed three areas to be examined during operational years. Similar to the 1973-1979 data analysis, ANOVA showed catches among years were significantly different and the Year x Area interaction was not significant (Table 43). Mean catches between areas were not significantly different, although the statistic was very close to being significant. Monthly and

Table 43. Analysis of variance summary for log(catch + 1) of yellow perch. Fish were gillnetted from June to September, 1975-1979 in Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df	Mean square	F-statistic	Attained significance
Year	4	1.1856	14.6120	0.0000**
Month	3	3.7364	46.0506	0.0000**
Area	2	0.4141	5.1037	0.0142
Depth	1	0.0816	1.0059	0.3259
Time	1	0.1586	1.9551	0.1748
Y x M	12	1.2793	15.7666	0.0000**
Y x A	8	0.0745	0.9180	0.5189
M x A	6	0.1481	1.8251	0.1365
Y x D	4	0.7337	9.0431	0.0001**
M x D	3	1.1515	14.1916	0.0000**
A x D	2	0.0235	0.2898	0.7510
Y x T	4	0.3391	4.1794	0.0104
M x T	3	0.1252	1.5427	0.2292
A x T	2	0.0506	0.6237	0.5444
D x T	1	1.0461	12.8925	0.0015*
Y x M x A	24	0.1554	1.9150	0.0592
Y x M x D	12	0.5961	7.3463	0.0000**
Y x A x D	8	0.0583	0.7187	0.6733
M x A x D	6	0.0440	0.5422	0.7709
Y x M x T	12	0.6492	8.0014	0.0000**
Y x A x T	8	0.1113	1.3719	0.2582
M x A x T	6	0.1649	2.0327	0.1004
Y x D x T	4	0.0797	0.9824	0.4357
M x D x T	3	0.0415	0.5119	0.6779
A x D x T	2	0.1363	1.6798	0.2076
Y x M x A x D	24	0.0553	0.6821	0.8224
Y x M x A x T	24	0.1354	1.6684	0.1086
Y x M x D x T	12	0.1325	1.6325	0.1482
Y x A x D x T	8	0.1378	1.6983	0.1503
M x A x D x T	6	0.0874	1.0778	0.4032
Y x M x A x D x T#	24	0.0811		

** Highly significant (P <0.001).
* Significant (P <0.01).
# The Y x M x A x D x T interaction is assumed to be zero and its mean square is treated as the within cell error mean square.

yearly catches at the north Cook area generally followed the pattern at the south Cook area except for 1976. For unknown reasons, in 1976 catches at the south Cook area declined after July, while north Cook catches continued to increase (Fig. 67). Overall mean catch at north Cook was less than at south Cook but still greater than at Warren Dunes. Lack of a significant difference in operational years' area catches consequently weakens our previous conclusion of an attraction by larger perch to the Cook area.

Seine Data--

Only the months of June, July, and August provided large enough and consistent enough catches of perch to be analyzed statistically. During most years, abundance of perch in the beach zone usually peaked in July (Fig. 68). ANOVA found yearly mean catches significantly different and the Year x Station interaction significant (Table 44). Station catches were not, however, significantly different.

Years--Scheffe's test revealed that the catches in 1974 and 1975 were significantly larger than other years' catches, while 1978 and 1979 catches were significantly smaller. Scheffe's test further showed that catch in preoperational years was significantly larger than the catch in operational years. While these findings suggest a plant effect, detailed examination of the catches reveals that only the very large catches in 1974 caused the significance in preoperational years. The catch in 1973 was not significantly larger than the other years' catch. Yearling yellow perch predominate in seine catches in the study areas and the large catch in 1974 was caused by a strong 1973 year class. Because yellow perch populations exhibit wide fluctuations in year-class abundance (Jobes 1952, El-Zarka 1959, Forney 1971),

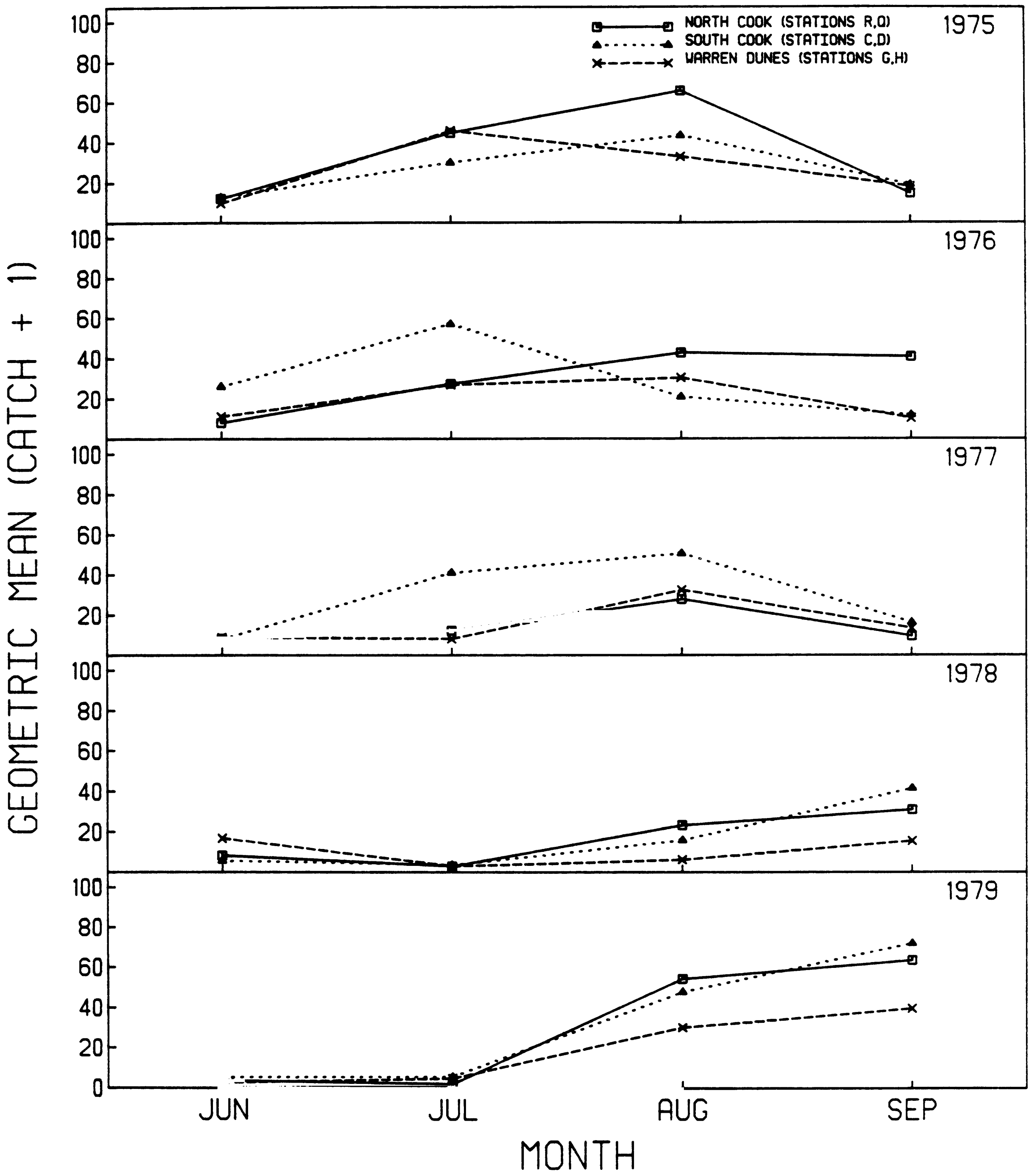


Fig. 67. Monthly geometric mean number of yellow perch caught during operational years 1975-1979 by standard series and stations R and Q gillnetting in Cook Plant study areas, southeastern Lake Michigan.

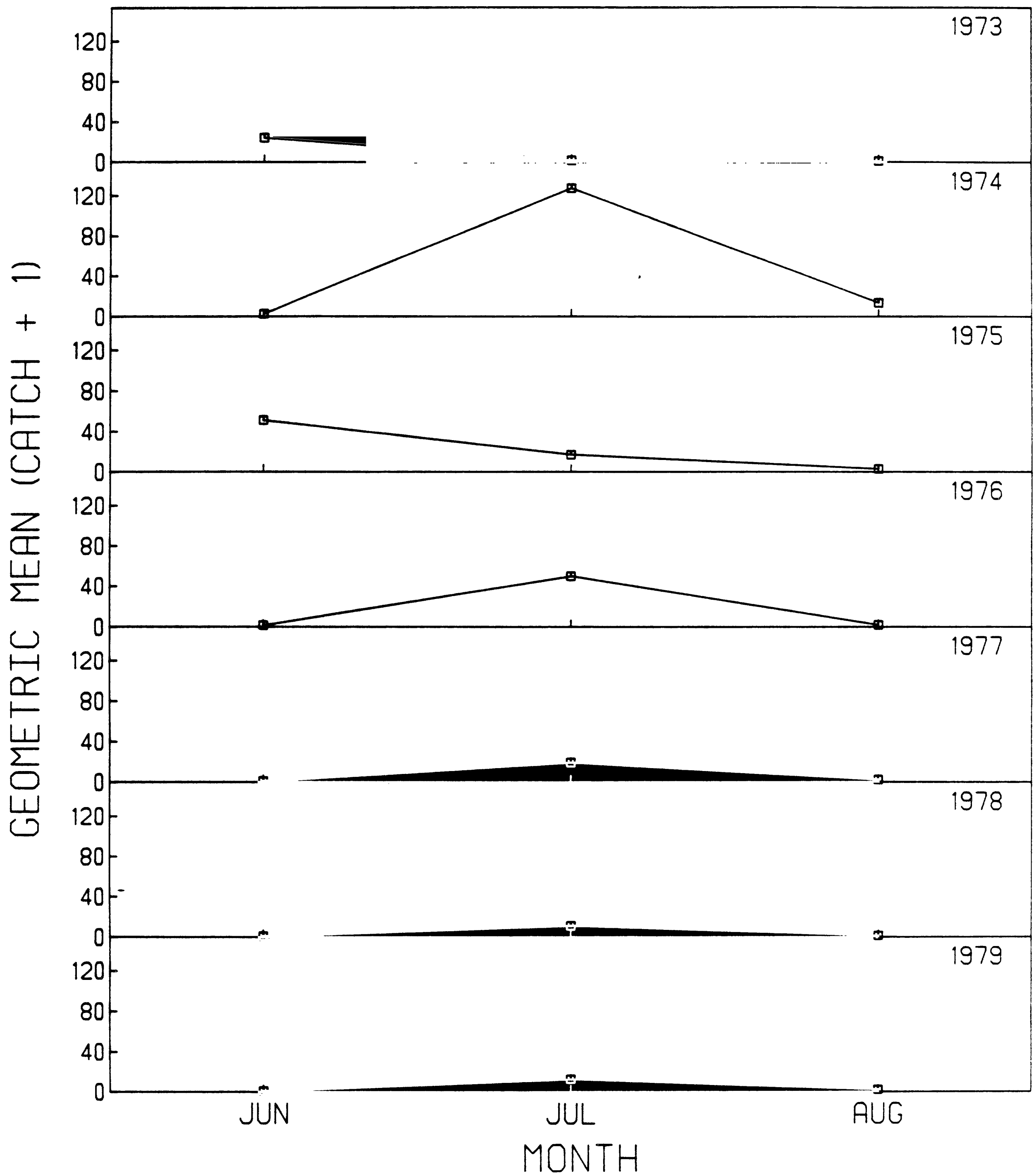


Fig. 68. Monthly geometric mean number of yellow perch caught by standard series seining in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

Table 44. Analysis of variance summary for log(catch + 1) of yellow perch. Fish were seined from June to August, 1973-1979 in Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df#	Adjusted mean square##	F-statistic	Attained significance
Year	6	3.8216	36.5629	0.0000**
Month	2	17.0149	162.7908	0.0000**
Station	2	0.1515	1.4492	0.2387
Time	1	3.4290	32.8070	0.0000**
Y x M	12	3.9480	37.7725	0.0000**
Y x S	12	0.2663	2.5475	0.0048*
M x S	4	0.1514	1.4486	0.2220
Y x T	6	0.3195	3.0564	0.0080*
M x T	2	3.5987	34.4304	0.0000**
S x T	2	0.8180	7.8261	0.0006**
Y x M x S	24	0.2235	2.1384	0.0037*
Y x M x T	12	0.9249	8.8486	0.0000**
Y x S x T	12	0.2284	2.1854	0.0161
M x S x T	4	0.3306	3.1627	0.0163
Y x M x S x T	24	0.3156	3.0196	0.0000**
Within cell error	125	0.1045		

One degree of freedom was subtracted from the error term to correct for a missing observation where the cell mean was substituted.

Mean squares were multiplied by harmonic cell size/maximum cell size (nh/n = 0.9921) to correct for one missing observation where the cell mean was substituted.

** Highly significant (P <0.001).

* Significant (P <0.01).

changes in yearly catch in the study areas appear to be natural fluctuations. Further evidence for this conclusion was the nonsignificance in area catches.

Areas--Monthly catches among the three stations were generally similar (Fig. 69). No one area had a consistently large or small catch during all study years. Thus no plant effects were documented. However, the Year x Station interaction was significant (Table 44). This significance appears to have resulted from the extreme differences in the 1974 catches, especially the

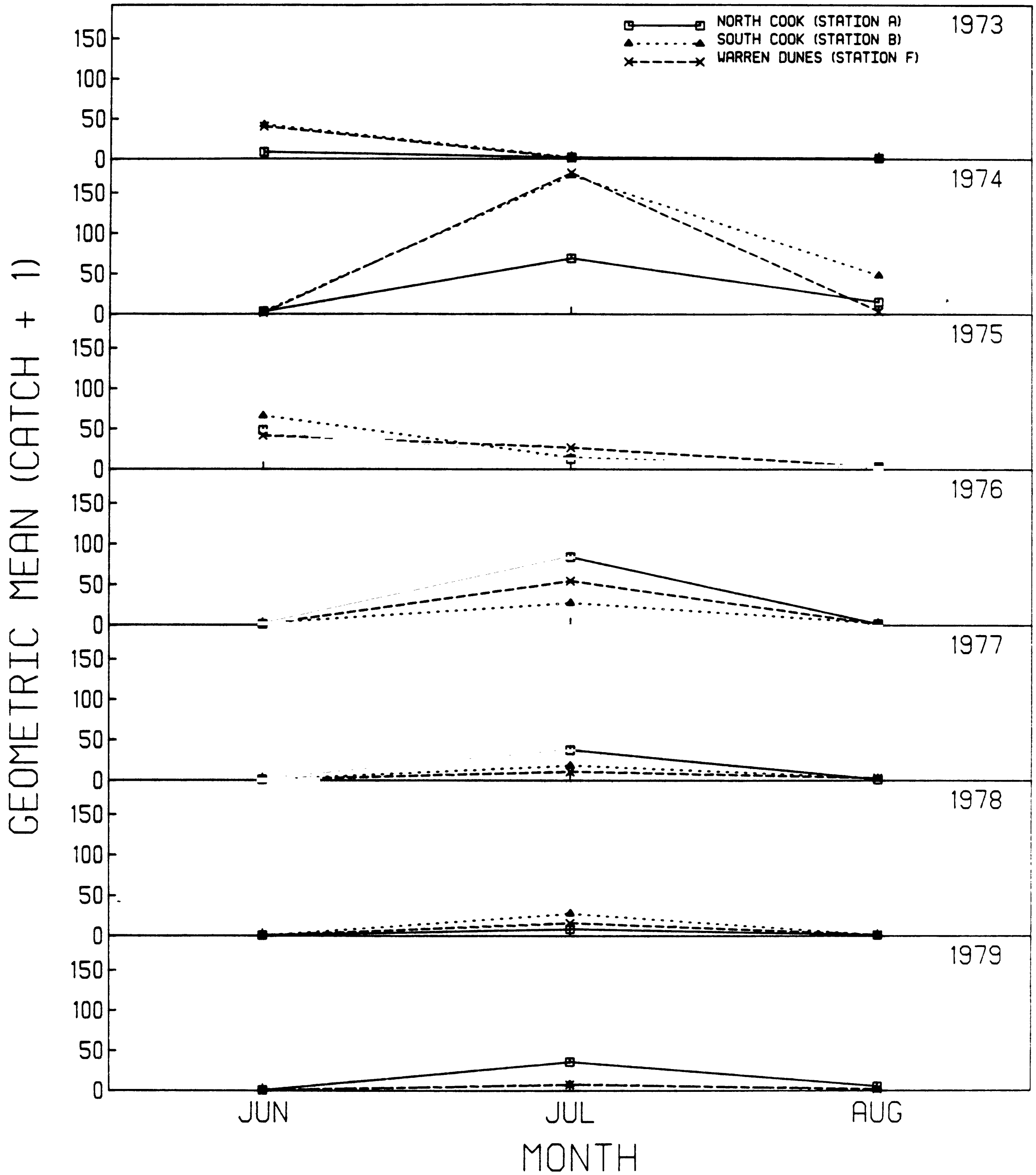


Fig. 69. Monthly geometric mean number of yellow perch caught by standard series seining in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

large catch at the north Cook area (Fig. 70). Catches in operational years were generally similar among the three areas. These results did not establish any plant effects on the yellow perch populations sampled by beach seining.

Summary of Operational Effects--

Statistical analyses of the trawl and seine catches of yellow perch identified some significant variations in the catches, however, plant effects were not established as a cause. Most variation was the result of natural population changes, e.g., strong and weak year classes, population-age structure changes, seasonal population movements, diel activity changes, contagious distribution of the perch population, and seasonal and local water temperature changes (Jude et al. 1979). Gill net catches did reveal a tendency for greater perch abundance at the Cook Plant during both preoperational and operational years. Large perch are attracted to the riprap and discharges at the plant site. This attraction places large perch in the vicinity of the plant's intakes and consequently may make the fish vulnerable to entrapment and ultimately impingement.

Distribution and Growth by Age-Group--

Examination of length-frequency histograms (Fig. 71) usually allowed separation of perch into three age-groups, YOY, yearlings, and adults. Occasionally during fall some overlap in sizes occurred between yearlings and adults (age 2+), but an approximate separation was still possible. These data showed that yearlings and adults predominated in the study areas. Yearlings constituted 46% of the total catch for all study years, while adults comprised 39% and YOY only 15%. Considerable variation in age structure occurred during individual years. Catches of adults varied almost 4-fold between the largest

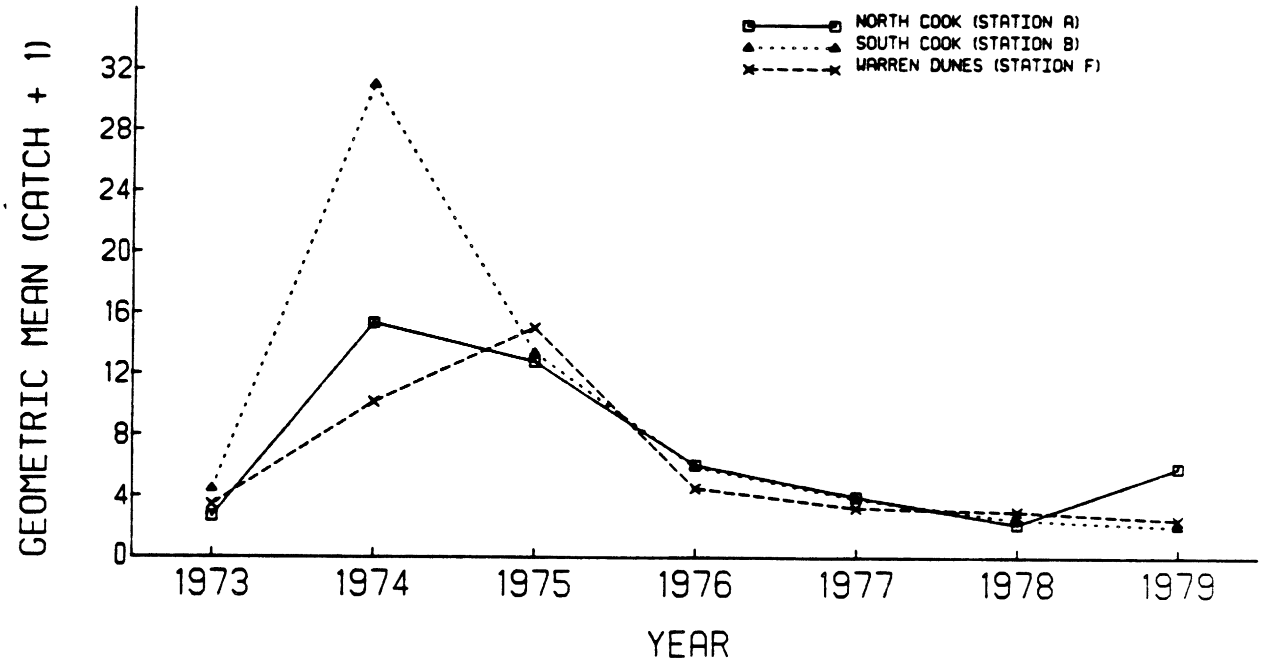


Fig. 70. Yearly geometric mean number of yellow perch caught by standard series seining in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

and smallest yearly catches, while yearlings varied 7-fold and YOY 28-fold. These substantial changes in yearly age structure undoubtedly contributed to the variation in the statistical analyses for plant effects.

Catch data for 1974 demonstrated how changes in age structure can confound statistical results. While trawl and gill net data showed that the catches in 1974 were significantly smaller than the other years' catches, seine data showed the opposite. While YOY and adult catches in 1974 were the smallest of the 7 yr, the yearling catch was the largest. Seines effectively sampled the yearlings, while trawls and gill nets did not. Thus, statistical results for this preoperational year were complex in relation to biological changes which ultimately complicates defining plant effects.

Abundance of YOY was not an accurate predictor of yearling abundance. For example, yearling abundance in 1974 was the greatest of the 7 years, how-

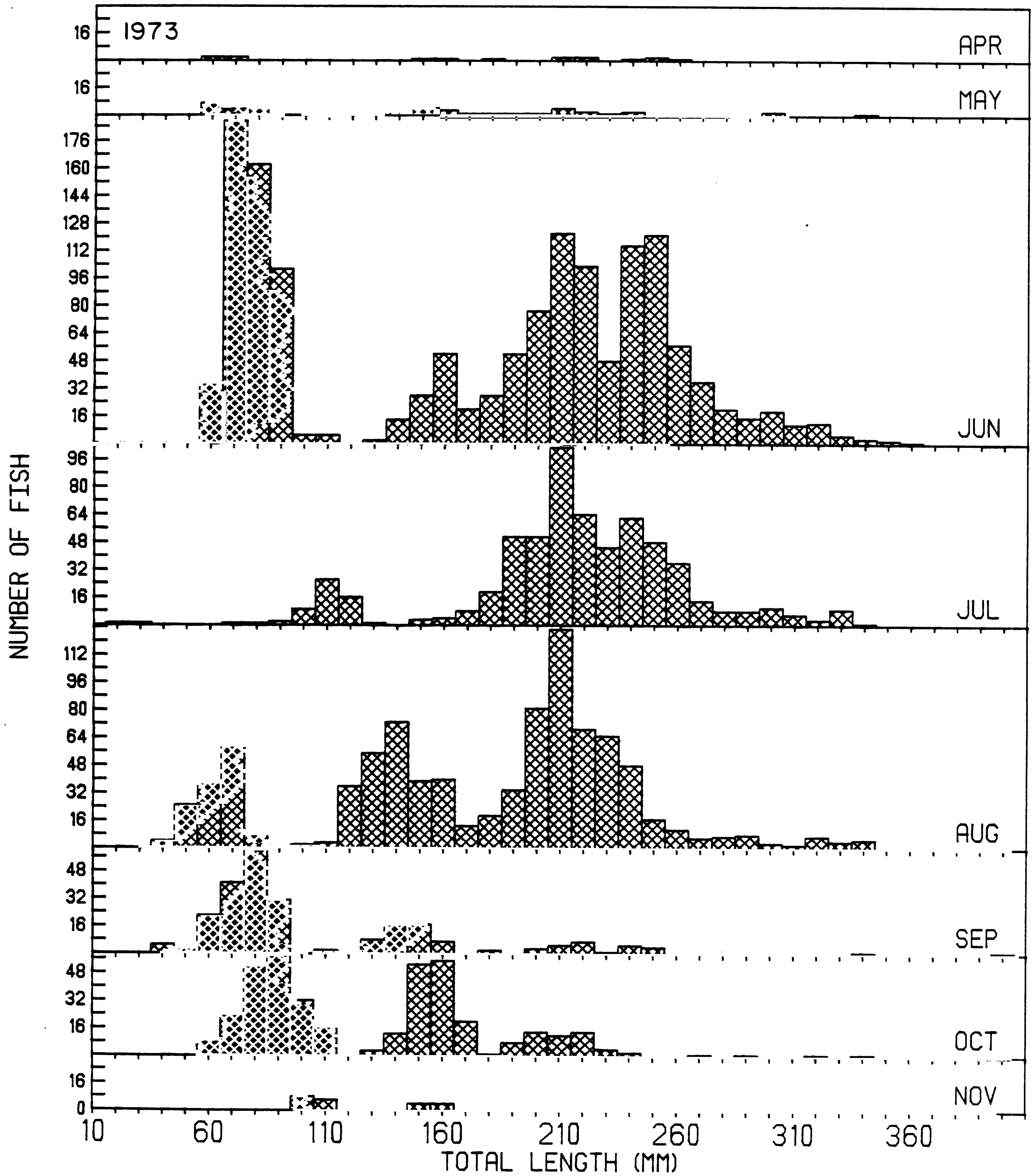


Fig. 71. Monthly length-frequency histograms of yellow perch caught during 1973-1979 by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan.

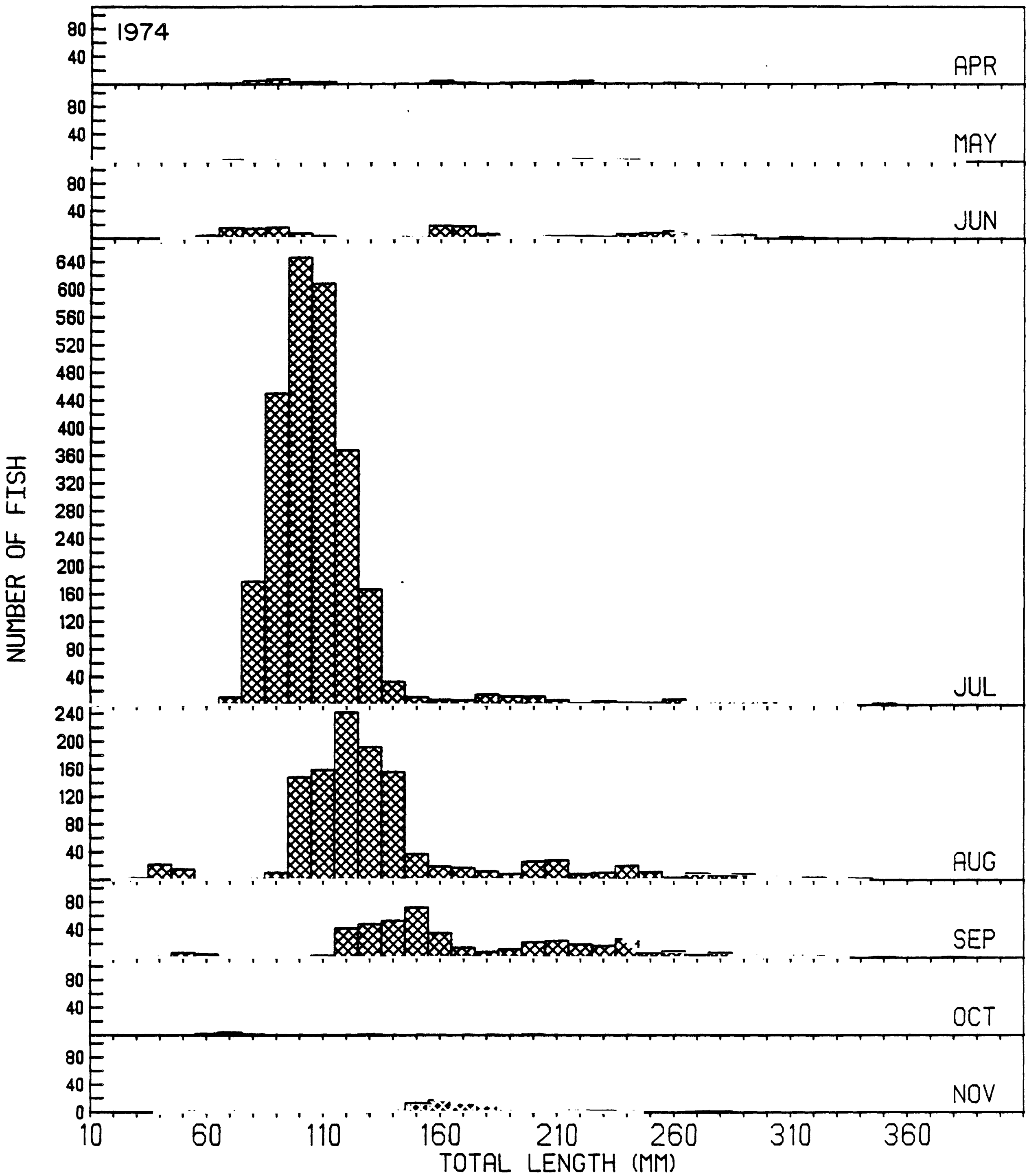
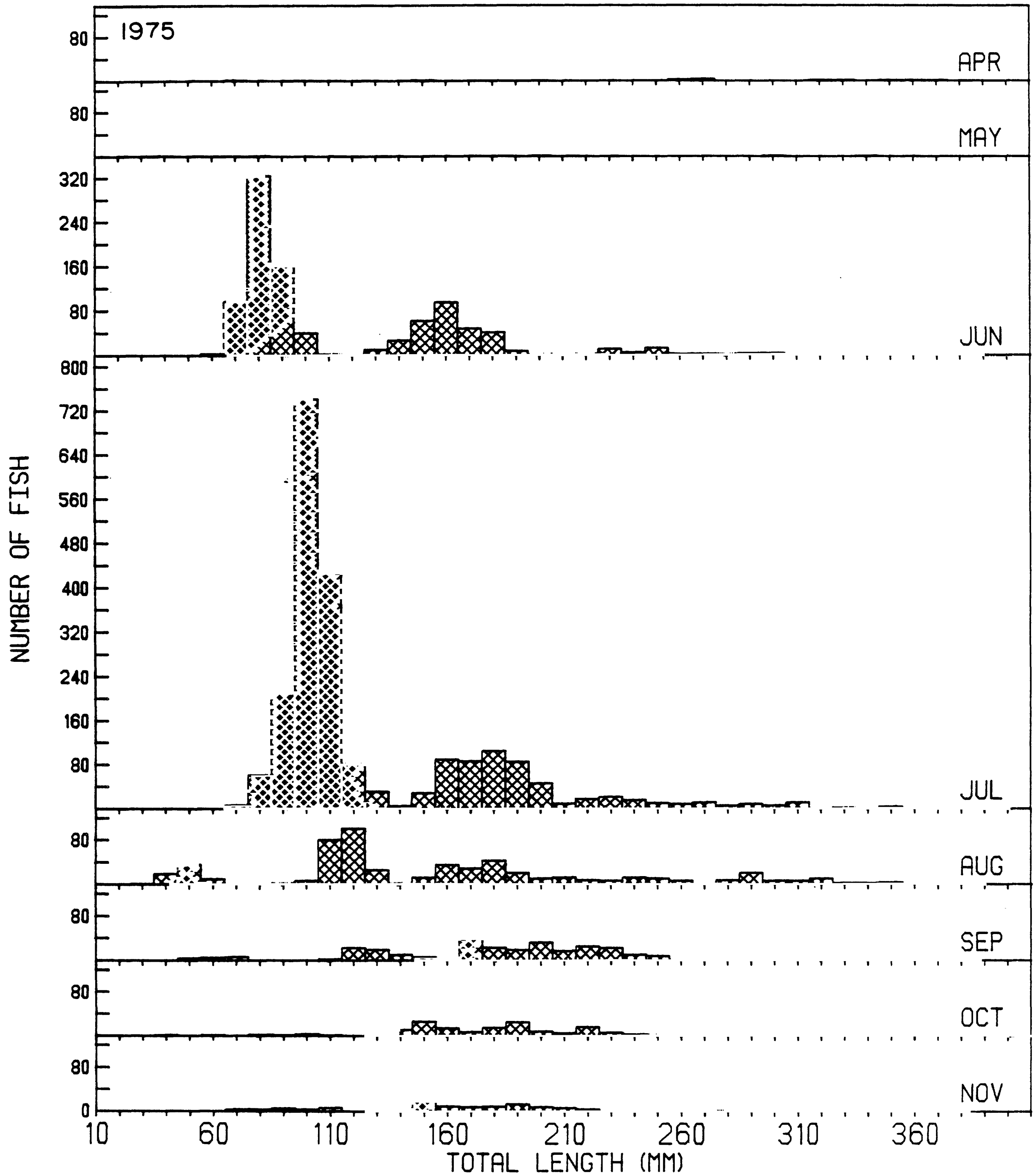


Fig. 71. Continued.



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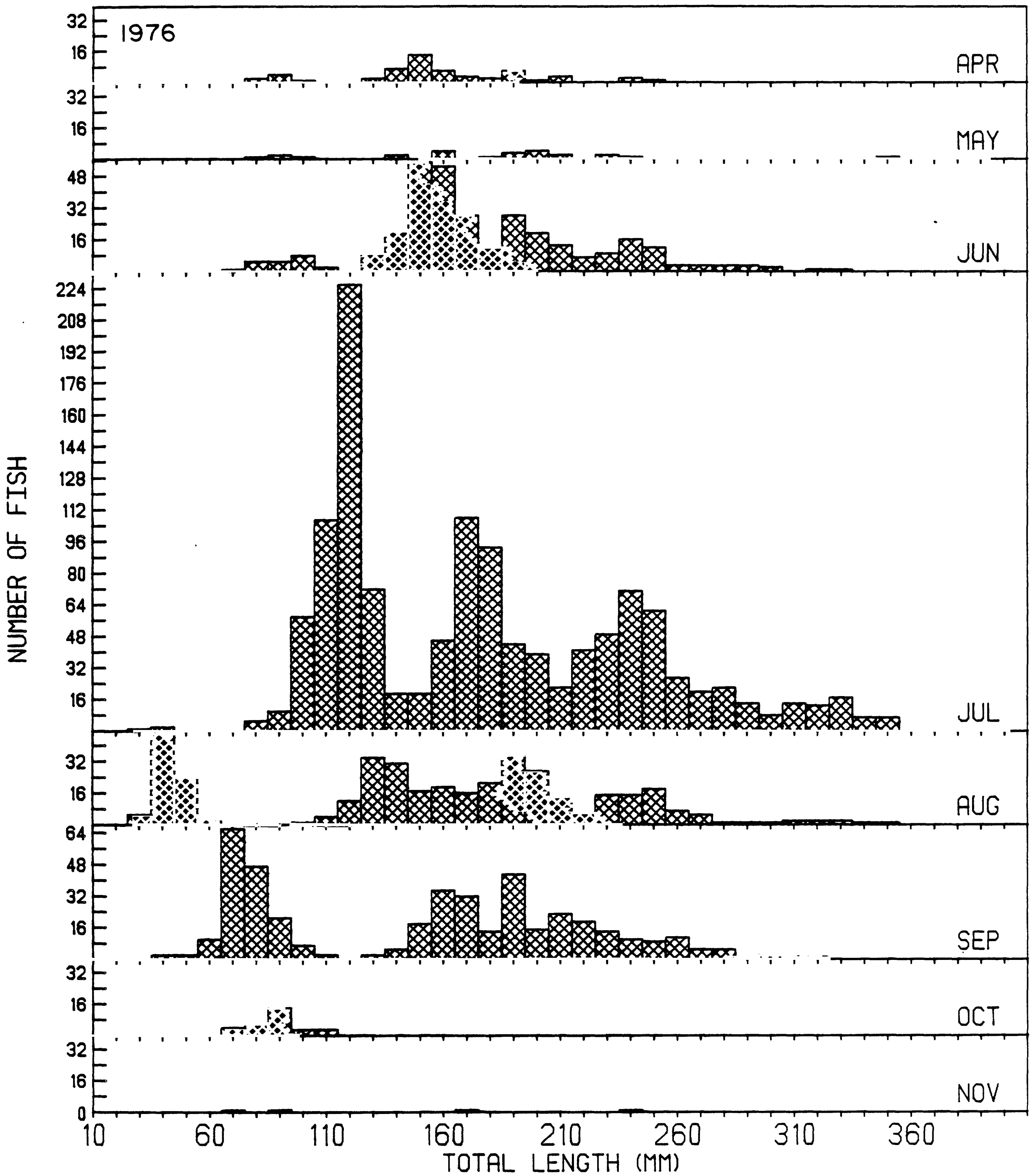

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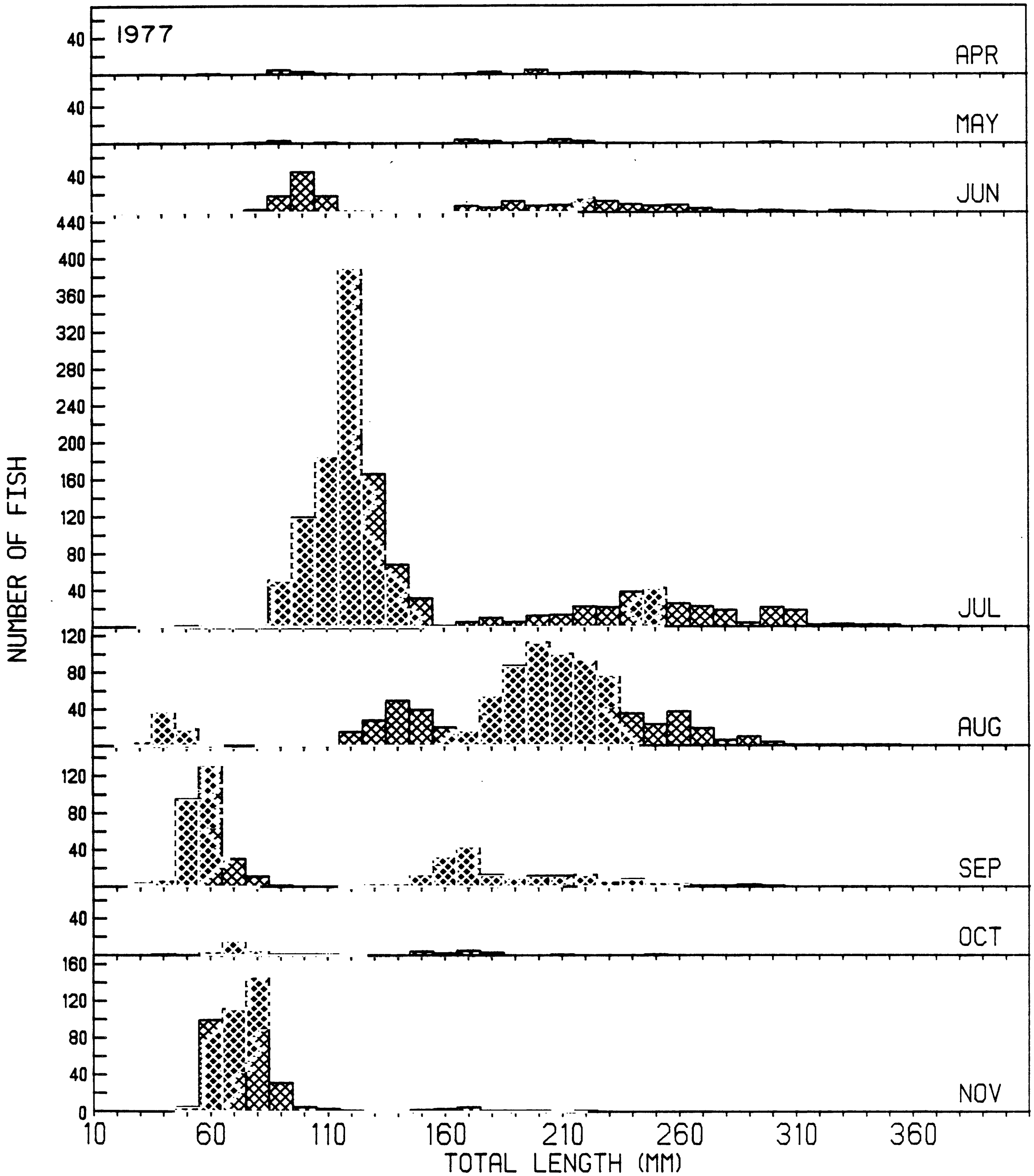
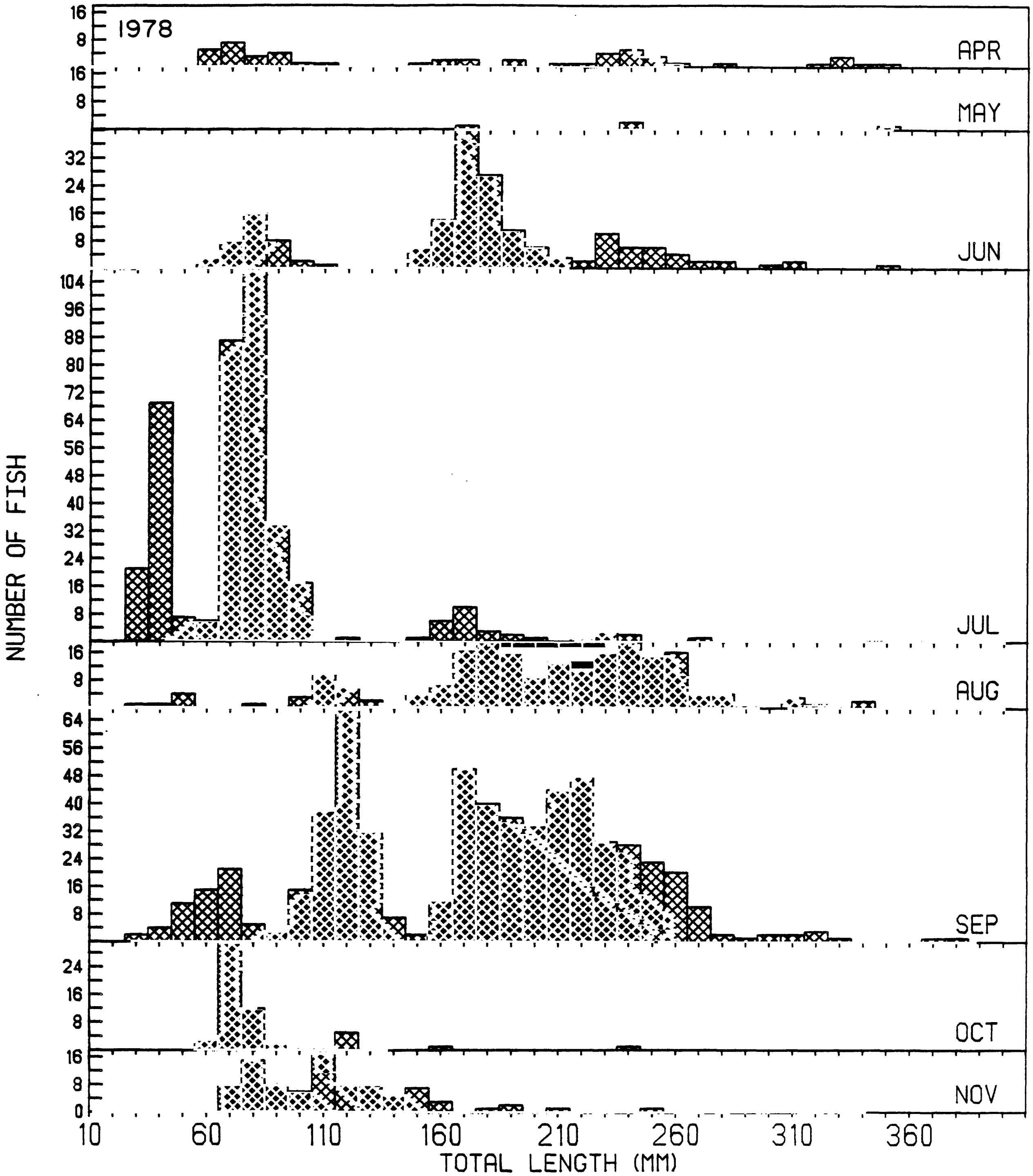


Fig. 71. Continued.



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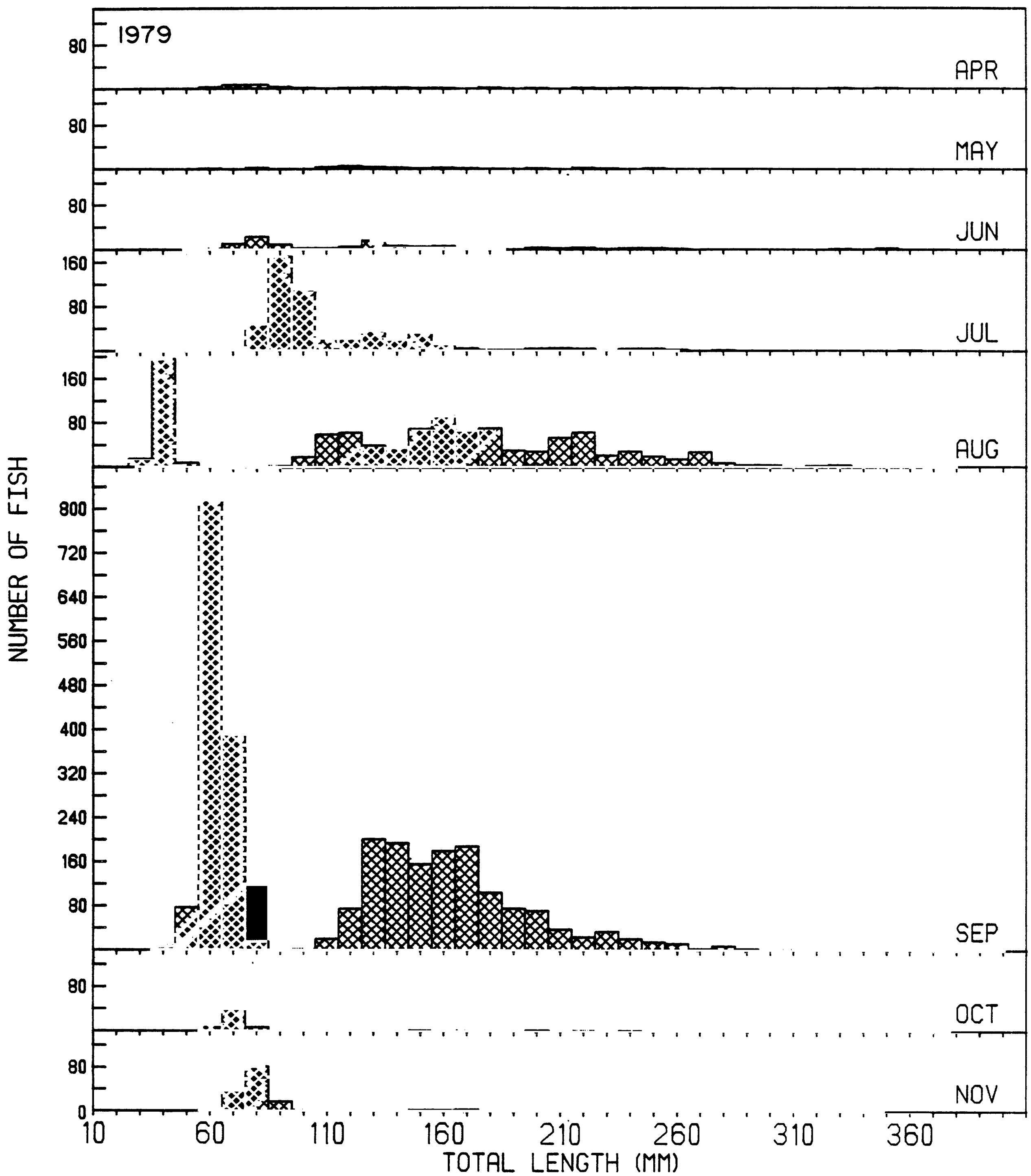


Fig. 71. Continued.

ever, YOY abundance in the previous year was about average. Second greatest abundance of yearlings occurred in 1975, but YOY abundance in 1974 was the smallest ever.

Young-of-the-year--August was the first month of the year that YOY were consistently collected, however in 1973, 1976, and 1978, YOY were first collected in July. During August and September, YOY were distributed from shore to 9 m during the day and night. Decreased seine catches at night in summer indicated a movement away from the beach zone, probably at dusk. During the fall, YOY began moving away from shore. At night, probably at dusk, the fish moved shoreward to 6 and 9 m. During December, most YOY were distributed deeper than 9 m, although some individuals were still as shallow as 9 m.

Changes in length of YOY perch, collected monthly, demonstrated variablility in monthly and yearly growth (Fig. 72). Growth was most rapid in summer and yearly growth was completed between October and November. During their first growing season yellow perch attained lengths between approximately 60 and 105 mm and averaged 81 mm. Lengths of YOY indicated that growth in 1973, 1975, and 1976 was above average while growth in 1974 was very poor.

To calculate growth rates, we assumed that yellow perch hatch at 5-6 mm (Auer 1982) and that they hatch near the study areas during the second week of June. Hatching time probably varies between late May to late June, but exact times each year could not be determined because of infrequent samples and lack of major spawning in the study areas. From June to August, YOY growth rate varied between 0.6 and 0.9 mm/day during the 7 years. These rates appear to be about average for yellow perch in North America (Jude et al. 1979). The August to October growth rate was 0.5 mm/day.

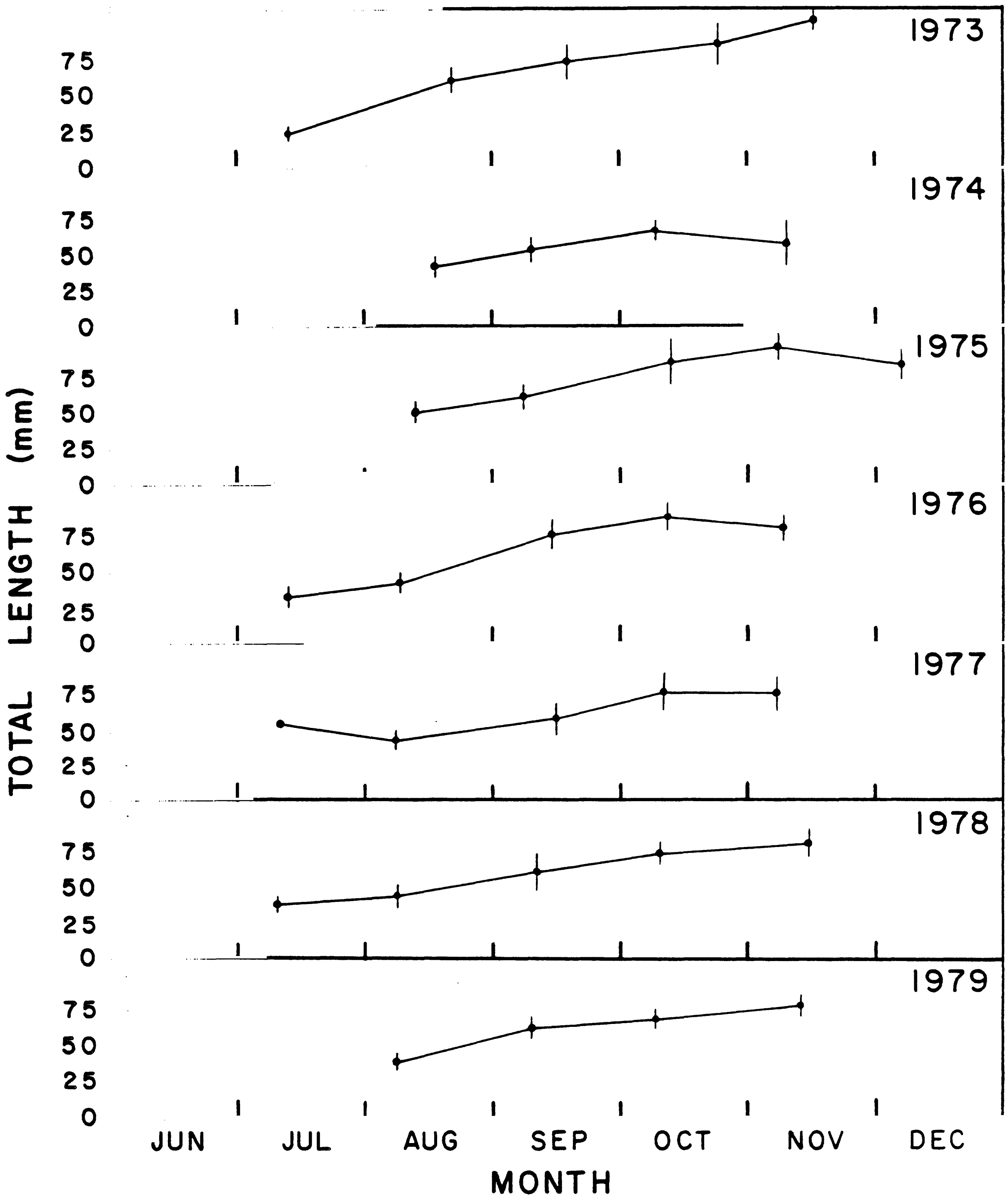


Fig. 72. Mean total length (± one standard deviation) of young-of-the-year yellow perch caught during 1973-1979 by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan.

Yearlings--During winter and spring, most yearlings were at depths greater than 9 m although some individuals were at 6 and 9 m. During June, yearlings began moving shoreward and were common at 6 and 9 m and occasionally at 1 m. In July, yearlings were concentrated inshore; large catches were common at 1 m. Yearlings moved out of the beach zone in August and were quite common at 6 m day and night. In September, yearlings were again concentrated at 6 m, but they were also commonly caught at 9 m during the day. During fall, yearlings appeared to be distributed deeper than 9 m during the day, but at night some individuals moved shoreward to 9 and 6 m. By December, yearlings were distributed deeper than 9 m but a few individuals were at 9 m.

Mean lengths of yearlings in spring varied from approximately 67 to 97 mm and overall averaged 82 mm (Fig. 73), a size similar to the 81-mm average length of YOY in the fall. Growth was most rapid in June, July, and August and appeared to be complete by October to November. Mean lengths of yearlings during fall ranged from 123 to 171 mm and overall averaged 152 mm. Growth of yearlings in the study areas was similar to yearling growth in southern Lake Michigan (Koch 1972); Oneida Lake, New York (Vashro 1975); and Lake Erie (Jobes 1952); but less than in northern Lake Michigan (Brazo et al. 1975). Finally, growth of yearlings from all of these areas was greater than growth reported for yearling yellow perch from most other waters of North America.

Adults--During fall, winter, and spring, adult yellow perch were distributed deeper than 9 m; however, a few individuals were caught at 6 and 9 m. Wells (1968) found a similar seasonal distribution of adult perch in southeastern Lake Michigan. Spawning occurs from late May to early June over rough substrates along the eastern and southeastern shore of Lake Michigan (Wells 1977, Dorr 1982). Our samples also indicated a late May spawning period as 82%

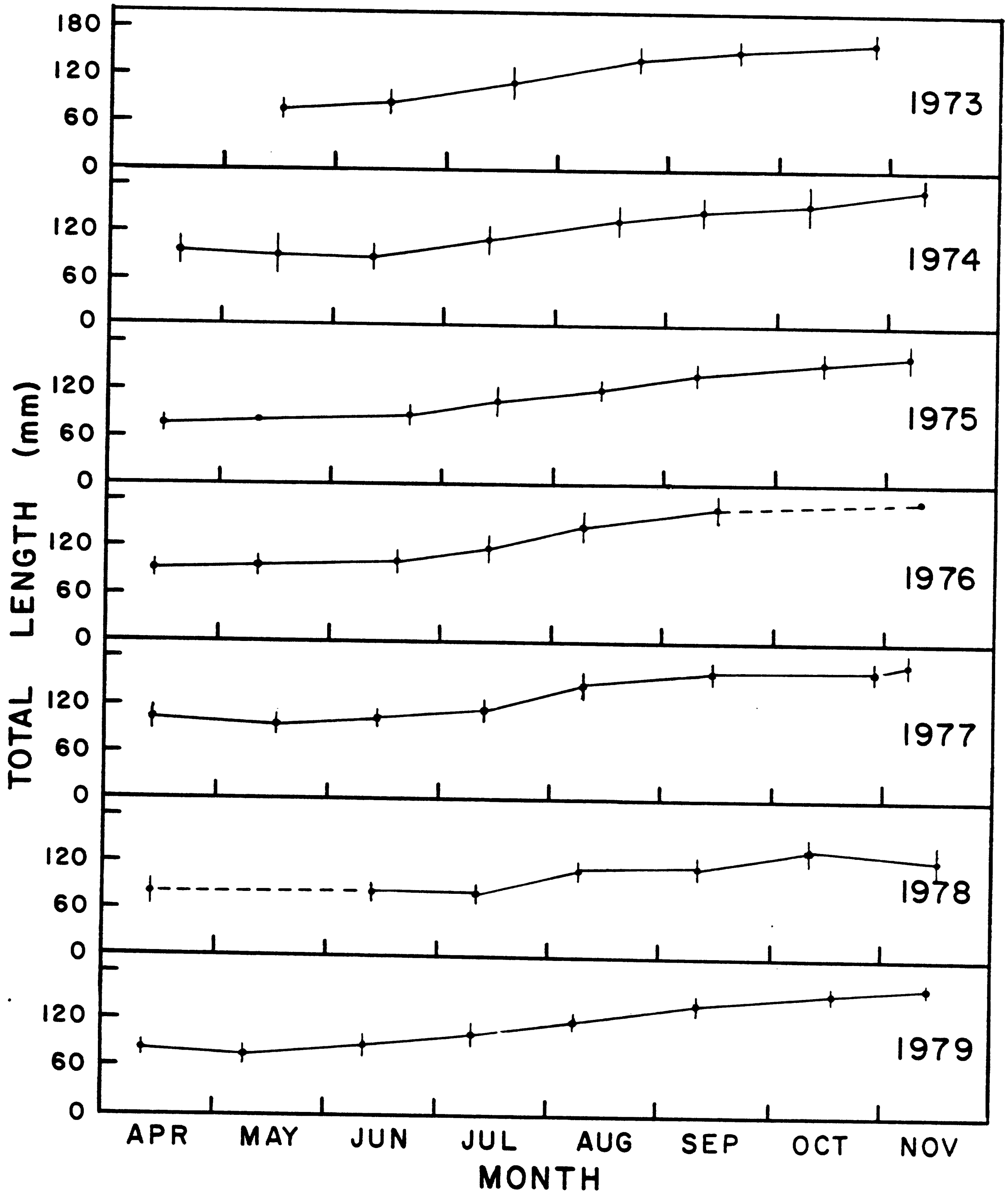


Fig. 73. Mean total length (+ one standard deviation) of yearling yellow perch caught during 1973-1979 by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan.

of the adult perch examined from May catches were ripe, while 87% of adults in June catches were spent (Table 45). Sampling in May and June usually occurred during the second week of the month. Because male yellow perch begin moving shoreward in early May (Brazo et al. 1975, Dorr 1982), small May catches in the study areas suggest that perch were not moving into these areas for spawning. An area of rough substrate exists approximately 3 km north of the plant and perch do move to this area to spawn (Dorr 1982). Some spawning occurs on the plant's riprap (Dorr and Jude 1980); however, this appears to be a limited effort by perch, probably because the area covered by riprap is not large compared to other areas of rough substrate in southeastern Lake Michigan.

From June to September in the study areas, adults were distributed at 6 and 9 m day and night. Occasionally, adults were caught in the beach zone in June and July, but most adults were distributed deeper than 1 m. By October most adults had moved deeper than 9 m.

Ages of adult perch were not determined; therefore, growth comparisons were not possible. Yellow perch are, however, attaining large sizes; some fish were up to 380 mm long.

Temperature-catch Relationships--

Sixty-seven percent of the perch were caught at temperatures between 18 and 24°C (Fig. 74). This relationship agrees with field observations, which indicate yellow perch prefer temperatures of 19-21°C (Ferguson 1958), and experimental results, which show a final temperature preference of 21-24°C (Scott and Crossman 1973). Laboratory experiments show that young perch select warmer water than adults (McCauley and Read 1973, Barans and Tubb 1973). Our catch data also show smaller fish were caught at higher temperatures than adults (Fig. 75).

Table 45. Number of ripe and spent yellow perch caught by standard series trawling, gillnetting and seining in Cook Plant study areas, southeastern Lake Michigan, 1973-1979. F = female, M = male, ND = no data.

Year	Sex	Gonad condition	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	F	Ripe	12	4	5	16	2	0	0	1	0	0
		Spent	0	0	0	342	140	179	29	11	0	0
	M	Ripe	8	3	10	31	5	1	5	4	0	0
		Spent	0	0	1	106	135	145	13	0	0	0
1974	F	Ripe	3	3	2	1	0	0	0	0	4	1
		Spent	0	0	0	35	66	40	42	0	0	0
	M	Ripe	1	7	5	7	2	0	0	40	2	0
		Spent	0	0	2	5	30	4	35	0	0	0
1975	F	Ripe	15	5	2	3	0	2	0	0	4	1
		Spent	0	0	0	16	87	51	14	1	0	0
	M	Ripe	8	4	0	29	0	2	0	4	34	3
		Spent	0	0	0	31	30	23	8	1	0	0
1976	F	Ripe	0	2	1	3	0	0	0	0	0	ND
		Spent	0	0	1	19	91	4	1	0	0	ND
	M	Ripe	2	26	4	5	1	0	12	0	1	ND
		Spent	0	0	2	70	58	4	0	0	0	ND
1977	F	Ripe	2	3	2	0	0	0	0	0	0	0
		Spent	0	0	0	63	55	80	1	0	0	0
	M	Ripe	3	15	1	5	2	2	5	0	6	0
		Spent	0	1	1	8	17	90	1	0	0	0
1978	F	Ripe	ND	5	1	0	0	0	0	0	1	ND
		Spent	ND	3	0	18	1	38	0	0	0	ND
	M	Ripe	ND	9	0	7	2	7	4	0	7	ND
		Spent	ND	0	1	1	0	17	0	0	0	ND
1979	F	Ripe	ND	0	1	4	0	2	0	0	0	ND
		Spent	ND	0	0	4	1	3	0	0	0	ND
	M	Ripe	ND	1	3	0	1	7	2	1	5	ND
		Spent	ND	0	0	3	0	8	0	0	0	ND

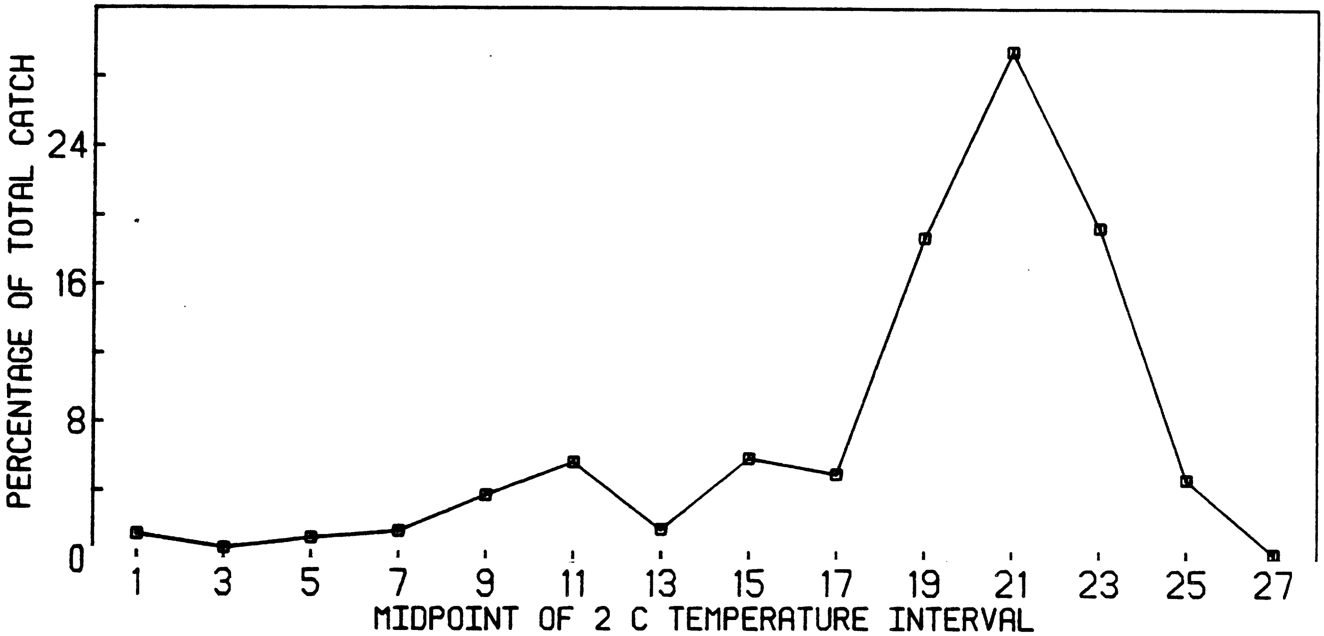


Fig. 74. Percentage of the combined total standard series catch of yellow perch collected during 1973-1979 from various temperatures in Cook Plant study areas, southeastern Lake Michigan.

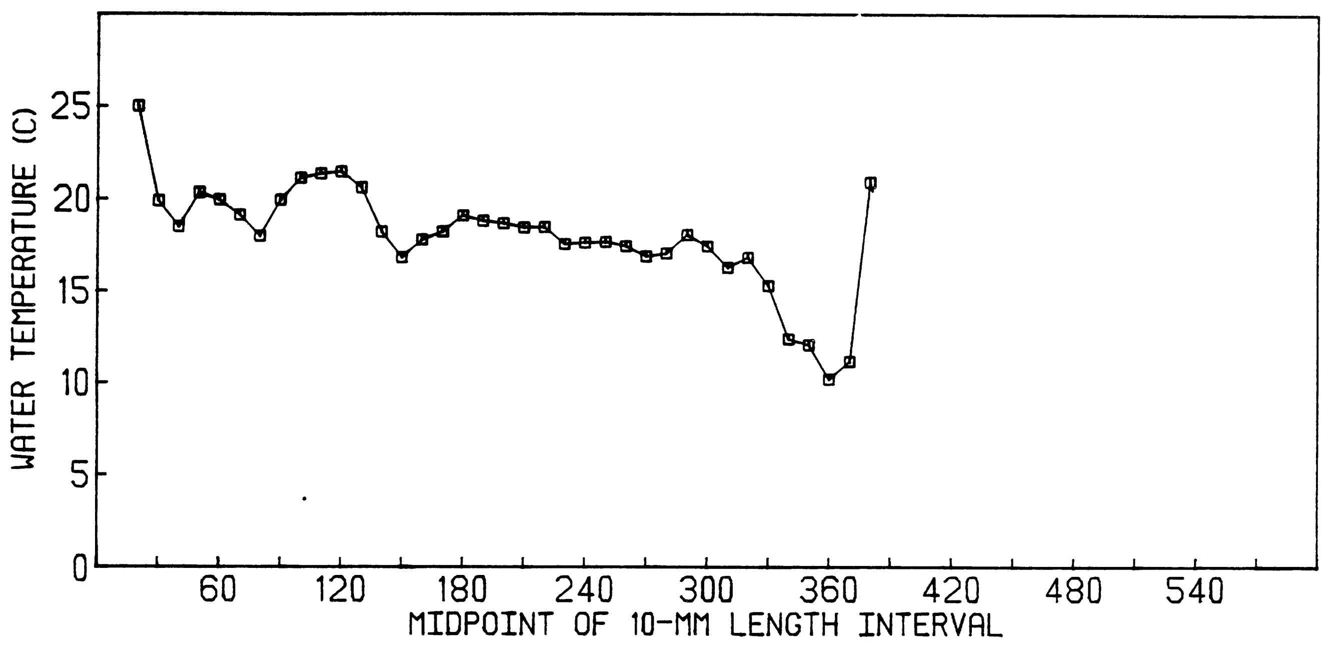


Fig. 75. Mean temperature at which different sizes of yellow perch were caught during 1973-1979 by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan.

COMMON SPECIES

Brown Trout

Operational Effects--

Brown trout were collected in low numbers during 1973-1979, accounting for less than 0.2% of the total fish catches. Most were caught in seines and gill nets. Only a few specimens occurred in trawls. Annual catches of brown trout were 78 and 51, respectively, during 1973 and 1974. During the operational period, brown trout were generally common, except in 1975 when relatively low catches (26) were made. Higher mean catches during the operational period (80) than the preoperational period (65) suggested possible effects of plant operation on brown trout populations.

Seine and gill net catches were generally similar at Cook and Warren Dunes stations during 1973-1974 (Tables 46 and 47). During 1975-1979, catches tended to be slightly higher at Cook than at Warren Dunes for both gill nets and seines. Mean gill net catches during the operational period were 21 fish at Cook and 14 at Warren Dunes. Mean seine catches at these two areas were 17 and 12 fish, respectively. Brown trout may be attracted to the plume area near the discharge at Cook. This species was reported to congregate in the area where heated water is discharged from power plants (Derickson et al. 1977).

Biological Data--

Brown trout were collected from March to November, with most being found in spring or early summer (Fig. 76). Brown trout 300 mm and larger generally migrated inshore during spring, presumably following the shoreward migration of alewives. Most of these larger individuals were caught in gill nets during

Table 46. Number of brown trout seined at standard series stations in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

		Cook Plant stations		Warren Dunes station
		North	South	
Year	Time Period	A	B	F
1973	Day	2	2	10
	Night	12	23	18
1974	Day	4	8	4
	Night	1	2	8
1975	Day	9	1	1
	Night	1	0	0
1976	Day	15	5	28
	Night	12	12	8
1977	Day	7	6	6
	Night	3	1	7
1978	Day	8	59	2
	Night	7	4	2
1979	Day	7	4	2
	Night	5	3	3

March-June. Juvenile brown trout 100-280 mm inhabited shallow water during May, June, and July when many were caught in beach seines. Most larger brown trout probably remained in deeper water during the summer due to warm water in the shallow areas; catches were small during July and August. Brown trout catches were generally low in the fall, suggesting upstream migration for spawning. Substantial numbers of brown trout were, however, collected during fall 1978 (Fig. 76).

Day and night catches of brown trout in gill nets were approximately the same. In seines, however, day catches tended to be higher than night catches (Table 47). These data suggested that young brown trout were more active

Table 47. Number of brown trout gillnetted at standard series stations and stations R and Q in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years. ND = no data.

		6-m stations			9-m stations		
		Cook Plant			Cook Plant		
		North	South	Warren Dunes	North	South	Warren Dunes
Year	Time Period	R	C	G	Q	D	H
1973	Day	ND	2	0	ND	1	2
	Night	ND	0	1	ND	0	4
1974	Day	ND	6	2	ND	2	1
	Night	ND	1	1	ND	5	4
1975	Day	1	0	0	1	3	0
	Night	3	4	1	2	5	1
1976	Day	3	2	0	1	0	0
	Night	4	3	0	3	3	2
1977	Day	4	5	2	0	3	0
	Night	12	4	9	3	4	4
1978	Day	15	10	5	7	18	12
	Night	18	9	19	13	4	2
1979	Day	9	14	5	6	0	1
	Night	5	7	6	1	1	1

during the day than at night. Brynildson et al. (1973), however, reported brown trout fed mostly in the evening, at night, and in the early morning and were generally inactive during the day.

Brown trout collected were in the 120- to 770-mm length interval (Fig. 77). Based on age-length data reported by Merron (1982), 100-270 mm brown trout we collected in spring and early summer were probably yearlings, whereas those 300 mm and larger were 2 years old or older. Yearlings from 100 to 270 mm in length represented approximately 60% of all brown trout collected. Annual

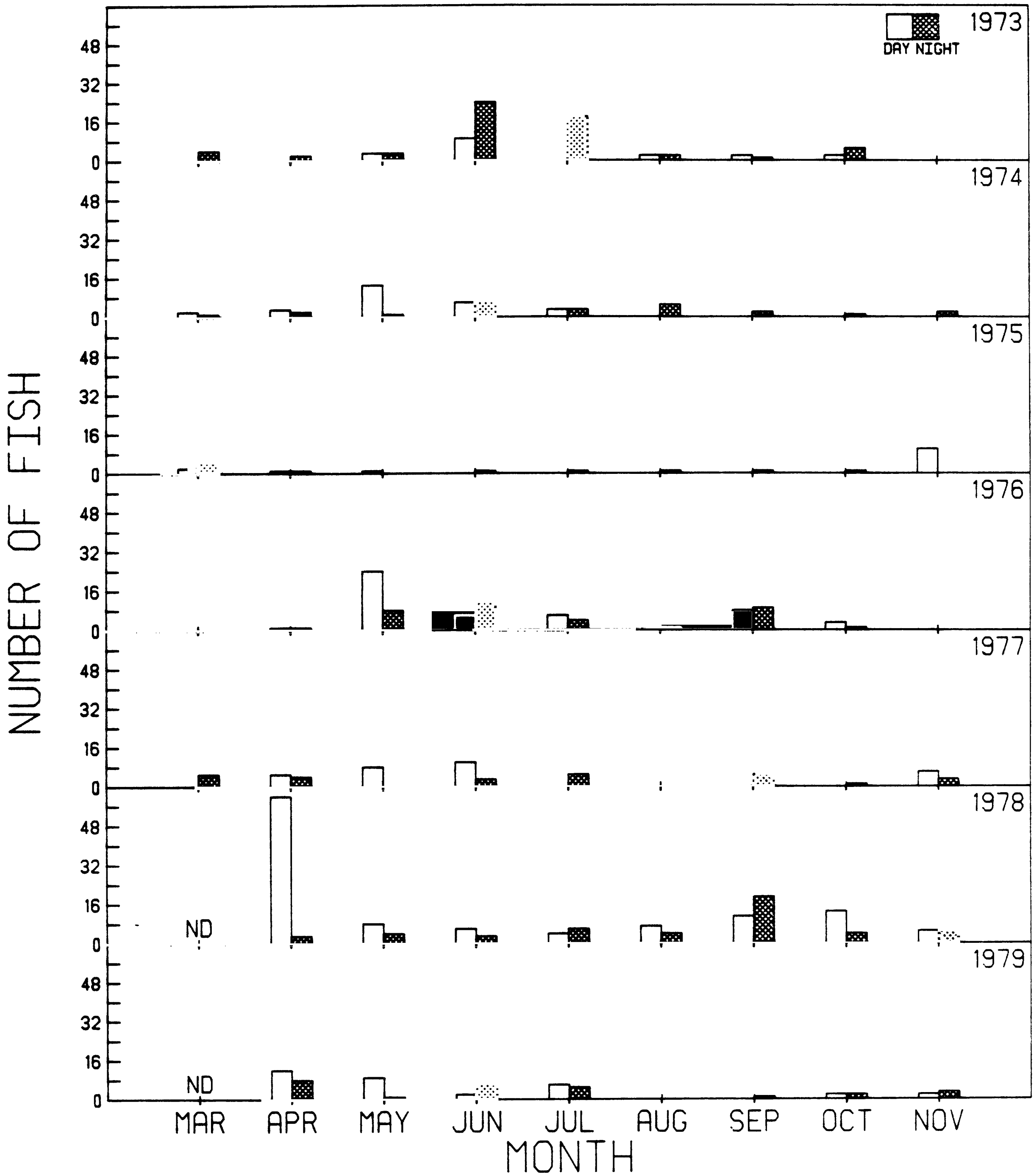


Fig. 76. Number of brown trout caught by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years. ND = no data.

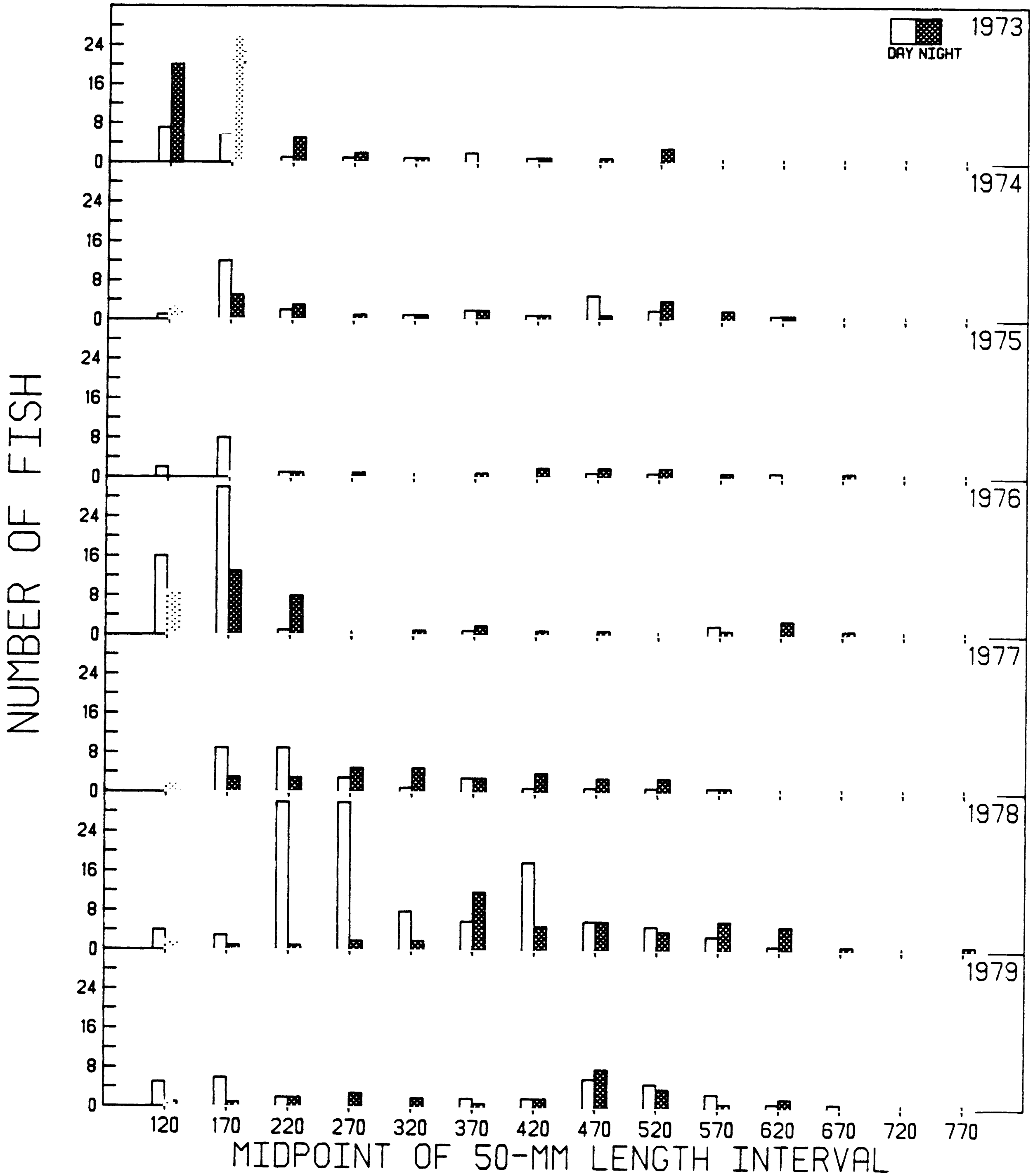


Fig. 77. Length-frequency histograms of brown trout caught by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

catches of yearlings fluctuated widely during 1973-1979, being largest in 1973, 1976, and 1978 (Fig. 77). Juvenile brown we collected may originate both from plantings and natural reproduction. Brown trout smaller than 100 mm probably remained in tributary streams because they have never been collected in the study area. Frost and Brown (1967) reported that offspring of lake-resident brown trout migrated downstream when about 1 year old.

Brown trout 300 mm and larger were relatively scarce during 1973-1977 (Fig 77). Substantial numbers of fish in this size range were collected in 1978 and 1979. This catch increase of larger brown trout may be related to the strong year classes in 1976, 1977, and 1978.

Brown trout spawn in streams in the fall (Brynildson et al. 1973). In our study area, ripe and spent adults were caught from August to November, suggesting that spawning took place in the fall. Low catches of brown trout during the fall may be related to upstream migration for spawning.

Most brown trout were caught in water temperatures of 7 to 17°C (Fig. 78). These data agreed with the final temperature preferendum of 12.4-17.6°C reported for brown trout (Ferguson 1958). Substantial numbers of brown trout were also collected in water temperatures of 19 to 24°C, suggesting that this species can tolerate relatively high temperatures.

Chinook Salmon--

Operational Effects--

Chinook salmon accounted for less than 0.2% of the total catches during 1973 - 1979. Juvenile chinook were caught mostly in seines, whereas adults

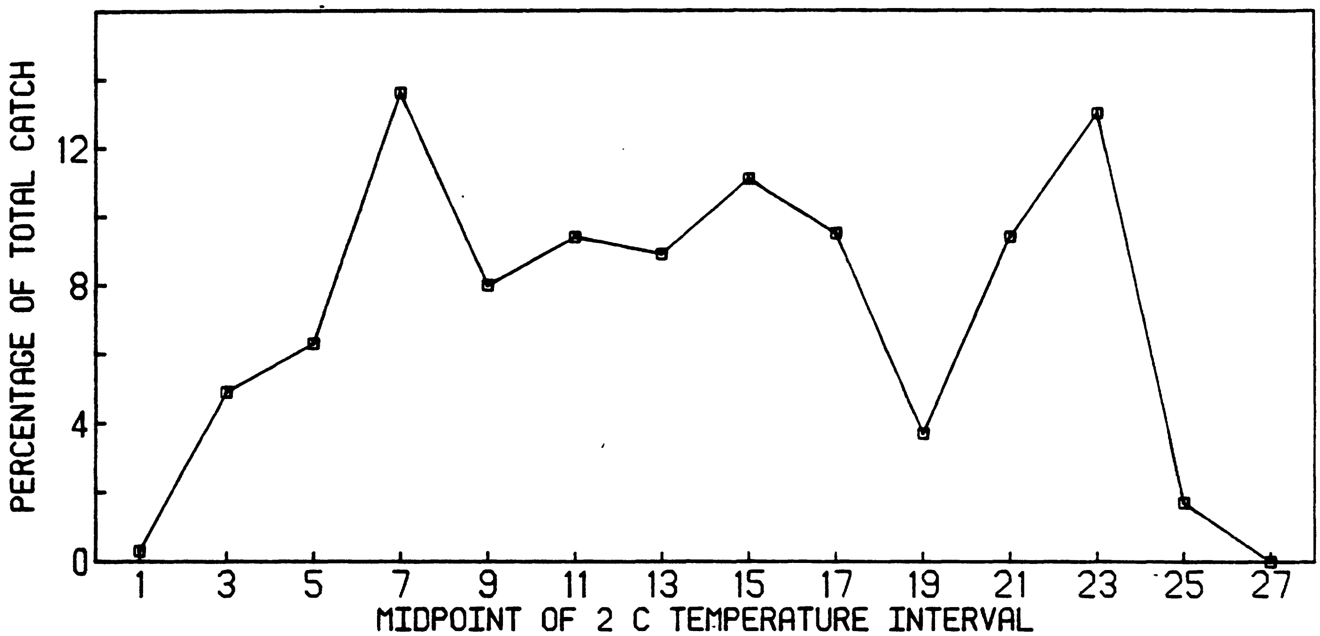


Fig. 78. Percentage of the combined total standard series catch of brown trout collected during 1973-1979 from various temperatures in Cook Plant study areas, southeastern Lake Michigan.

occurred mostly in gill nets. Low numbers of chinook salmon were found in trawls. Gill net data were analyzed by non-parametric statistics for possible effects of plant operation on chinook salmon populations. The Kruskal-Wallis test showed significant catch differences among years during 1973-1979 (Table 48). Gill net catches varied widely, ranging from 4 in 1976 to 52 in 1978 (Table 49). Catches during preoperational years (1973-1974) were not significantly different from those during the operational period (1975-1979). Catches were also similar among the preoperational period (1973-1974), the one-unit operational period (1975-1978), and the two-unit operational period (1979). However, when 1978 was included in the two-unit operational period,

Table 48. Results of the Kruskal-Wallis test (nonparametric ANOVA) applied to 1973-1979 chinook salmon gill net catch data from Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df	H statistic	Attained significance
Station (G, H, C, D, R, Q)	5	1.4527	0.9185
Area (Warren Dunes, south Cook, north Cook)	2	0.1403	0.9323
(Warren Dunes, Cook Plant)	1	0.1403	0.7080
Year (1973-1979)	6	15.3800	0.0175*
(1973-74, 1975-79)	1	0.6825	0.4087
(1973-74, 1975-78, 1979)	2	4.5041	0.1052
(1973-74, 1975-77, 1978-79)	2	10.1950	0.0061*
(1973-74, 1975-77, 1978, 1979)	3	13.5720	0.0035*
Depth (6 m, 9 m)	1	0.7325	0.3921
Time (day, night)	1	32.9410	0.0000*

* Significant ($P < 0.1$).

catches were significantly higher than those during the preoperational period (1973-1974). These conflicting statistical results were due to the unusually large catches in 1978. Catches at Cook and Warren Dunes during the operational period were not significantly different. Mean annual gill net catches at Cook and Warren Dunes during 1975-1979 were 14 and 17, respectively. These data indicated that plant operation had no effect on chinook salmon catches.

Seine catches increased every year from 1973 to 1979, except in 1976 when catches declined from the 1975 level (Table 50). Mean seine catches during the operational period (80) were substantially higher than those during the preoperational period (12), suggesting possible plant effects. Mean annual seine catches at Cook (27) and at Warren Dunes (25) during the operational period were, however, similar, indicating that plant operation had little impact on chinook salmon in the beach zone. The increased seine catches

Table 49. Number of chinook salmon gillnetted at standard series stations and stations R and Q in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years. ND = no data.

		6-m stations			9-m stations		
		Cook Plant			Cook Plant		
		North	South	Warren Dunes	North	South	Warren Dunes
Year	Time Period	R	C	G	Q	D	H
1973	Day	ND	0	0	ND	0	1
	Night	ND	1	3	ND	5	2
1974	Day	ND	1	0	ND	0	0
	Night	ND	4	4	ND	3	11
1975	Day	0	0	0	1	0	0
	Night	0	4	8	4	11	9
1976	Day	0	0	0	0	0	0
	Night	0	1	1	1	1	1
1977	Day	0	0	0	0	0	0
	Night	15	4	9	18	10	10
1978	Day	0	0	1	0	4	1
	Night	5	4	23	11	9	10
1979	Day	2	2	3	6	4	3
	Night	6	6	10	6	8	4

during the operational period may be in part related to increased natural reproduction of chinook salmon and to an increase in chinook plantings in the vicinity of the study area during 1978-1979. The number of chinook smolts annually planted in the Saint Joseph River in 1978 (300,000) fish and 1979 (250,000) were higher than in previous years (200,000).

Biological Data--

Chinook salmon occurred from April to November. A few specimens were also collected during March in 1977. Monthly catches were generally higher

Table 50. Number of chinook salmon seined at standard series stations in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

		Cook Plant stations		Warren Dunes station
		North	South	
Year	Time Period	A	B	F
1973	Day	2	3	0
	Night	2	2	1
1974	Day	2	4	3
	Night	4	1	0
1975	Day	0	0	1
	Night	1	7	8
1976	Day	0	4	0
	Night	0	1	5
1977	Day	4	15	15
	Night	4	3	1
1978	Day	0	0	0
	Night	0	45	10
1979	Day	88	52	71
	Night	28	24	13

during spring than summer or fall (Fig. 79). During 1974, 1975, and 1978 a slight catch increase was observed during September and October. Spring catches were larger during 1977-1979 than during previous years. Chinook salmon generally moved inshore during April, May, and June, probably in pursuit of alewives which migrated inshore during spring. Planted chinook smolts migrated downstream during spring; most were caught during April, May, and June. Catches were generally low during July and August, suggesting that chinook salmon avoided warm water in the inshore area. Although adults returned to the shallow area during fall, fall catches were relatively low. Parsons (1973) reported anglers caught more adult chinook during fall than in spring or summer.

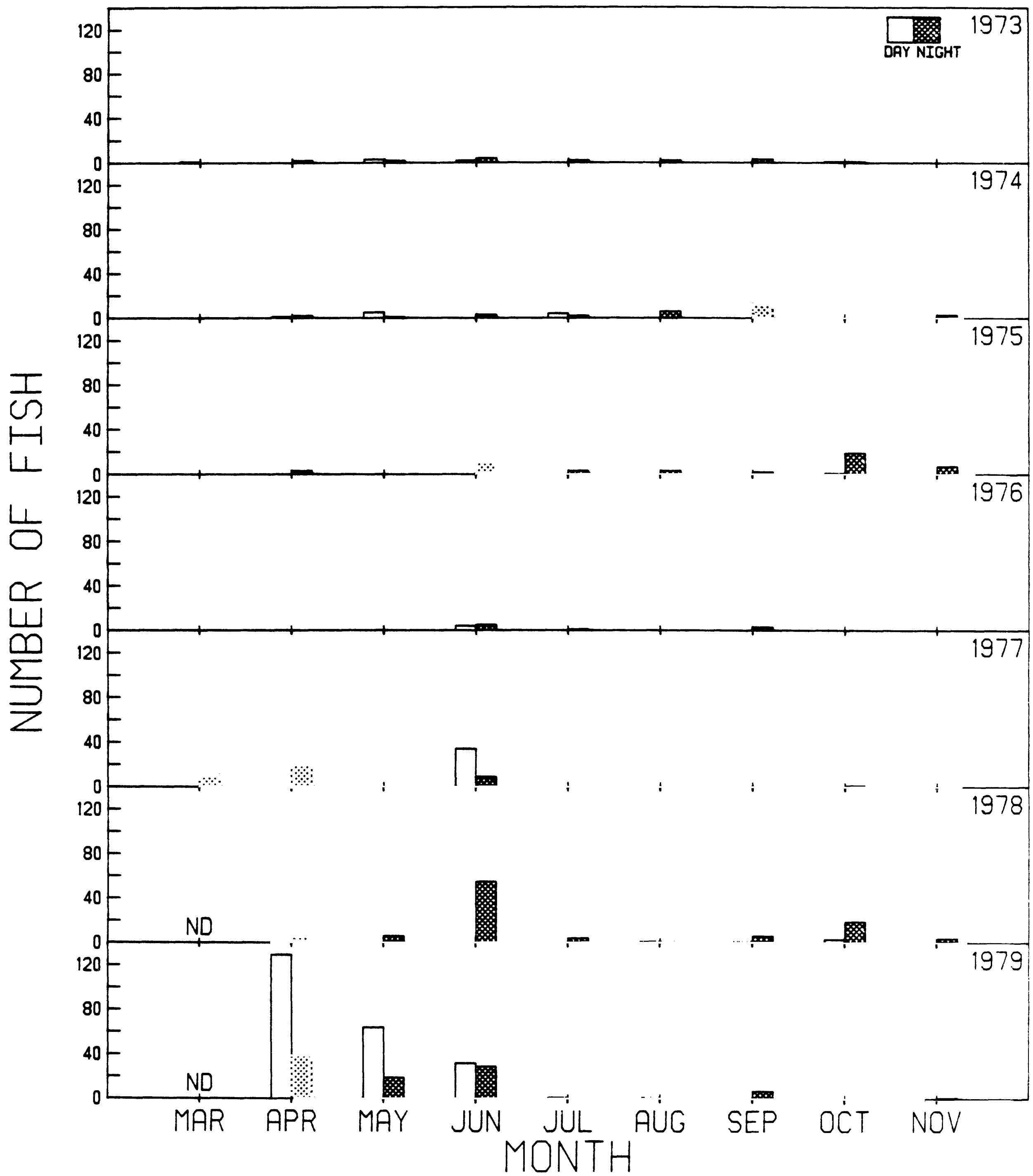


Fig. 79. Number of chinook salmon caught by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years. ND = no data.

The Kruskal-Wallis test revealed that night catches were significantly larger than day catches. Larger chinook remained close to shore at night. They were probably in deep water or were able to avoid gill nets during the day. Day catches in gill nets were comprised primarily of juveniles 80-330 mm. Juveniles were probably more active during the day than at night. More juveniles were seined during the day than at night.

Chinook salmon we collected ranged in length from 60 to 980 mm, most were 60- to 300-mm juveniles (Fig. 80). Chinook salmon are 51-76 mm when planted in spring (Parsons 1973). Juveniles collected in our study area reached 60-170 mm during April-July, and 150-300 mm during August-November. Age-1 chinook salmon were 220-310 mm during February-April and 410-510 mm in the fall. In Lake Superior, chinook salmon reached a smaller size (300-350 mm) at the end of the second year of life (Berg 1978). These data agreed with Parsons (1973) who reported chinook salmon grow faster in Lake Michigan than Lake Superior.

Chinook salmon in the Great Lakes spawn in the fall (Berg 1978). Most adult chinook we collected in September were ripe-running, indicating that spawning took place during this month in southeastern Lake Michigan. Low catches of adults in the fall may be related to spawning, which occurs in streams.

Most adult chinook salmon were caught in water temperatures of 5 to 17°C; whereas juveniles 70-280 mm were found in water temperatures of 9 to 20°C. Preferred temperatures of YOY chinook were 12 to 13°C (Brett 1952). Gray et al. (1977) found no evidence of attraction of young chinook salmon to heated discharge water.

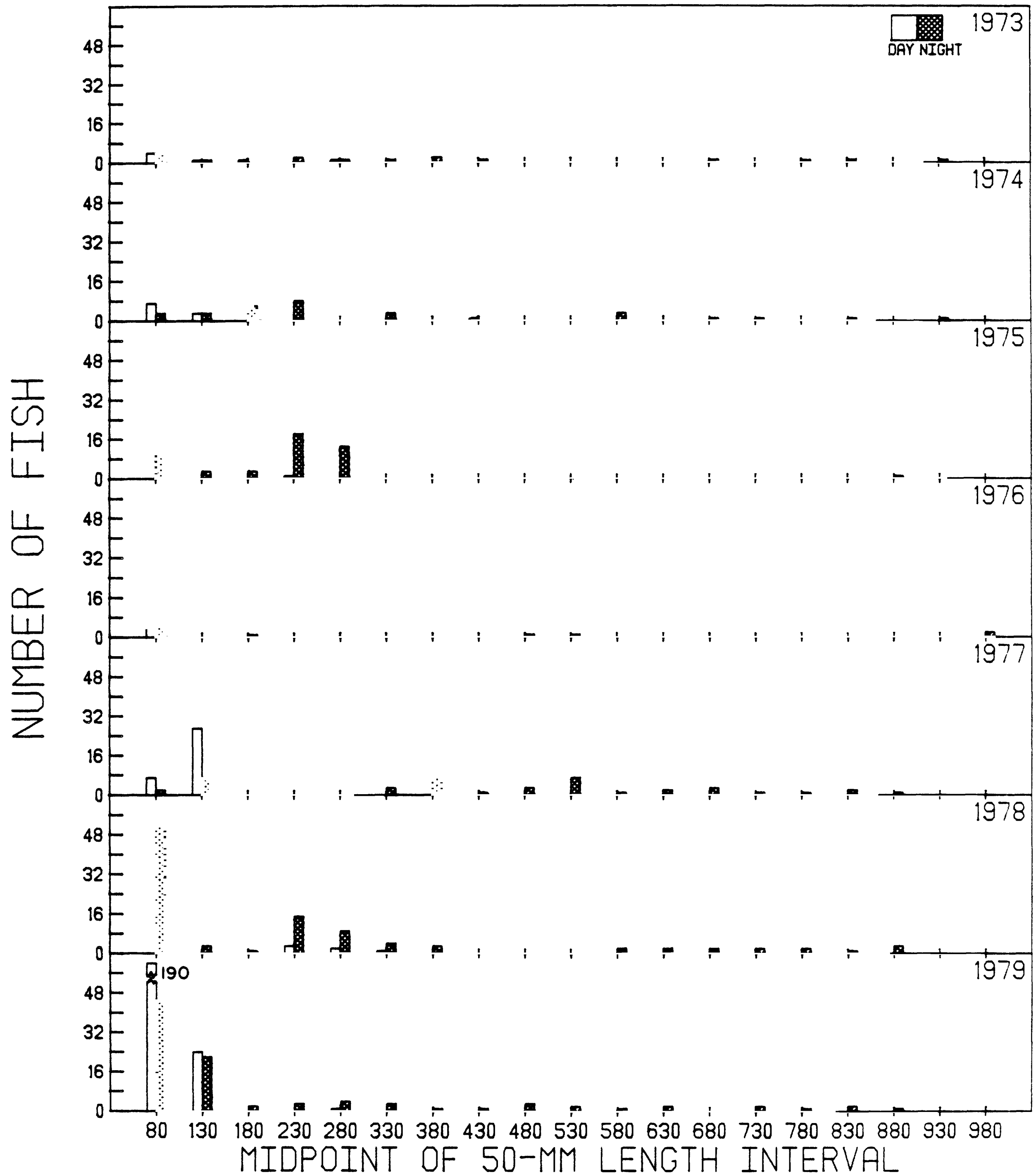


Fig. 80. Length-frequency histograms of chinook salmon caught by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

Coho Salmon

Operational Effects--

Coho salmon represented less than 0.4% of the annual catches during 1973-1979. Most were caught in beach seines and gill nets. Only two specimens were collected in trawls. Annual catches of coho salmon varied considerably, ranging from 29 in 1973 to 301 in 1978. Catch fluctuations were observed during both preoperational and operational periods (Tables 51 and 52). During 1975-1979, mean annual catches of coho salmon at Cook stations (46) were comparable to those at Warren Dunes stations (39). These data suggested that plant operations had little impact on the distribution of coho salmon.

Catch fluctuations were due to variations in juvenile and adult catches. Catches of juvenile coho salmon were generally related to planting of coho smolts in the vicinity of the study area. Small catches of juveniles in 1973 (6) and 1975 (9) may be related to the lack of planting in the St. Joseph River in Berrien County during these 2 years; larger catches during 1974 and 1976-1979 corresponded to smolt plantings at the above site. However, despite the same level of planting (192,000 to 203,000 smolt per year), juvenile catches fluctuated from 26 to 252 during 1976-1979. Adult catches ranged from 10 in 1977 to 78 in 1974.

Coho salmon catches were relatively large during spring and generally declined during summer and fall (Fig. 81). Three-year-old coho salmon migrated inshore during spring. Engel and Magnuson (1971) observed similar inshore movement of adult coho in spring. Coho may have followed the alewives which were also inshore by this time. Substantial numbers of coho were caught in gill nets during April, May, and June (Fig. 81). During summer, adults evidently resided in deeper water outside the study area due to increased

Table 51. Number of coho salmon gillnetted at standard series stations and stations R and Q in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years. ND = no data.

		6-m stations			9-m stations		
		Cook Plant		Warren Dunes	Cook Plant		Warren Dunes
		North	South		North	South	
Year	Time Period	R	C	G	Q	D	H
1973	Day	ND	2	0	ND	0	3
	Night	ND	8	3	ND	3	1
1974	Day	ND	7	4	ND	8	6
	Night	ND	12	11	ND	30	25
1975	Day	9	1	1	0	1	1
	Night	17	16	8	16	20	7
1976	Day	1	0	1	4	2	0
	Night	8	12	2	3	6	2
1977	Day	0	0	0	1	0	0
	Night	4	3	2	3	0	2
1978	Day	1	1	2	1	2	2
	Night	5	11	13	5	4	16
1979	Day	5	12	7	1	4	1
	Night	3	2	1	0	2	0

inshore water temperatures. Low catches in the fall may be related to upstream migration for spawning.

Catches of juveniles also showed seasonal fluctuations. Juvenile coho salmon from planting and natural reproduction migrate downstream to lakes in spring. High catches were observed in the study area during April, May, and June. These data agreed with those of Tody and Tanner (1966) who reported coho smolts remained near shore upon first entering the sea. Juvenile catches declined during summer and fall due to offshore migration. During August 1974, when cold water was inshore, substantial numbers of young coho were seined.

Table 52. Number of coho salmon seined at standard series stations in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

		Cook Plant stations		Warren Dunes station
		North	South	
Year	Time Period	A	B	F
1973	Day	0	0	3
	Night	3	3	0
1974	Day	11	7	4
	Night	10	10	8
1975	Day	0	0	0
	Night	2	5	1
1976	Day	6	8	1
	Night	3	3	0
1977	Day	18	39	20
	Night	4	6	2
1978	Day	45	93	79
	Night	25	1	5
1979	Day	13	0	18
	Night	1	2	2

Most adults were caught in gill nets; and most juveniles in seines. In gill nets, more coho salmon were collected at night than during the day. Adult coho salmon probably moved closer to shore at night; they may also be able to avoid gill nets during the day. In contrast to gill nets, seines captured more coho salmon during the day than at night. Godfrey (1965) reported more coho smolts migrated downstream at night than during the day. Peck (1974), however, found no significant difference between day and night catches of young coho salmon during their migration from streams to Lake Michigan.

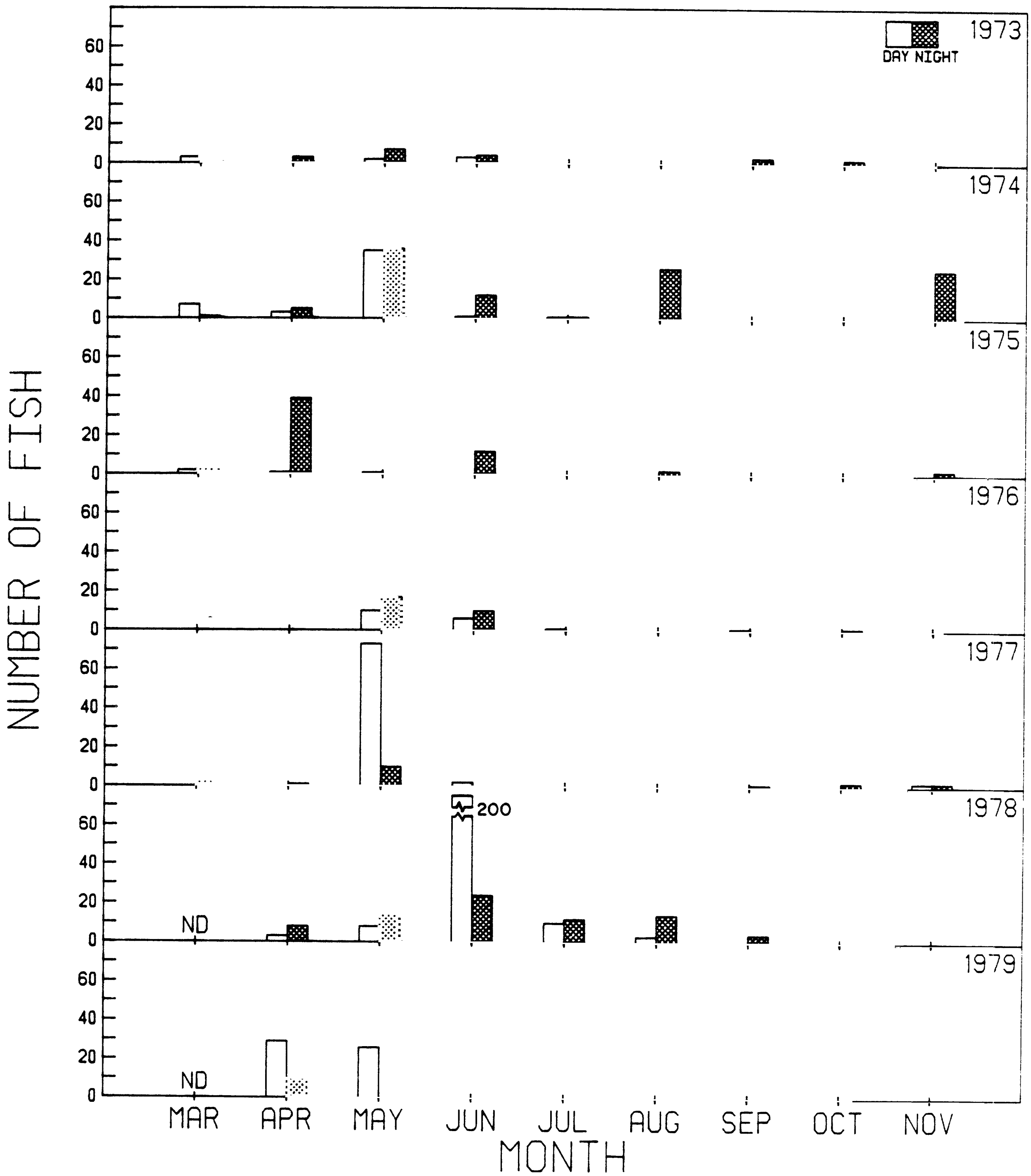


Fig. 81. Number of coho salmon caught by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years. ND = no data.

Biological Data--

Coho salmon collected were in the 60- to 880-mm length intervals. Juveniles 250 mm and smaller represented 65% of the total catches during 1973-1979 (Fig. 82). Coho salmon grow rapidly in Lake Michigan, and most growth takes place during the second summer of life (Stephenson 1968). At planting time, juveniles are 100 to 152 mm; during spring of the third year of life, adults are 400 to 550 mm (Parsons 1973). During summer and fall, most 3-year olds in the study area were 500 mm and larger. This size was comparable to that of adults from other areas of Lake Michigan, which were over 506 mm during the fall 1978 and 1979 spawning runs (Patriarche 1980).

Coho salmon spawn in the fall. All adults collected in September showed ripe-running gonads, indicating that the spawning run started this month in the vicinity of the Cook Plant. Low catches of adults during September, October, and November were probably due to the congregation of spawners at the mouth of tributary streams outside the study area.

Approximately 75% of all coho salmon were caught in water temperatures of 8-17°C (Fig. 83). Engel and Magnuson (1971) found most coho salmon in comparable water temperatures (8-16°C) during summer. The final temperature preferendum for coho salmon was 11.4°C during spring (Reutter and Herdendorf 1974). Adults were caught in a wider range of temperatures than juveniles. Juvenile coho 60-240 mm occurred in water temperatures of 12-20°C, whereas adults were caught in water temperatures of 5-25°C (Fig. 84).

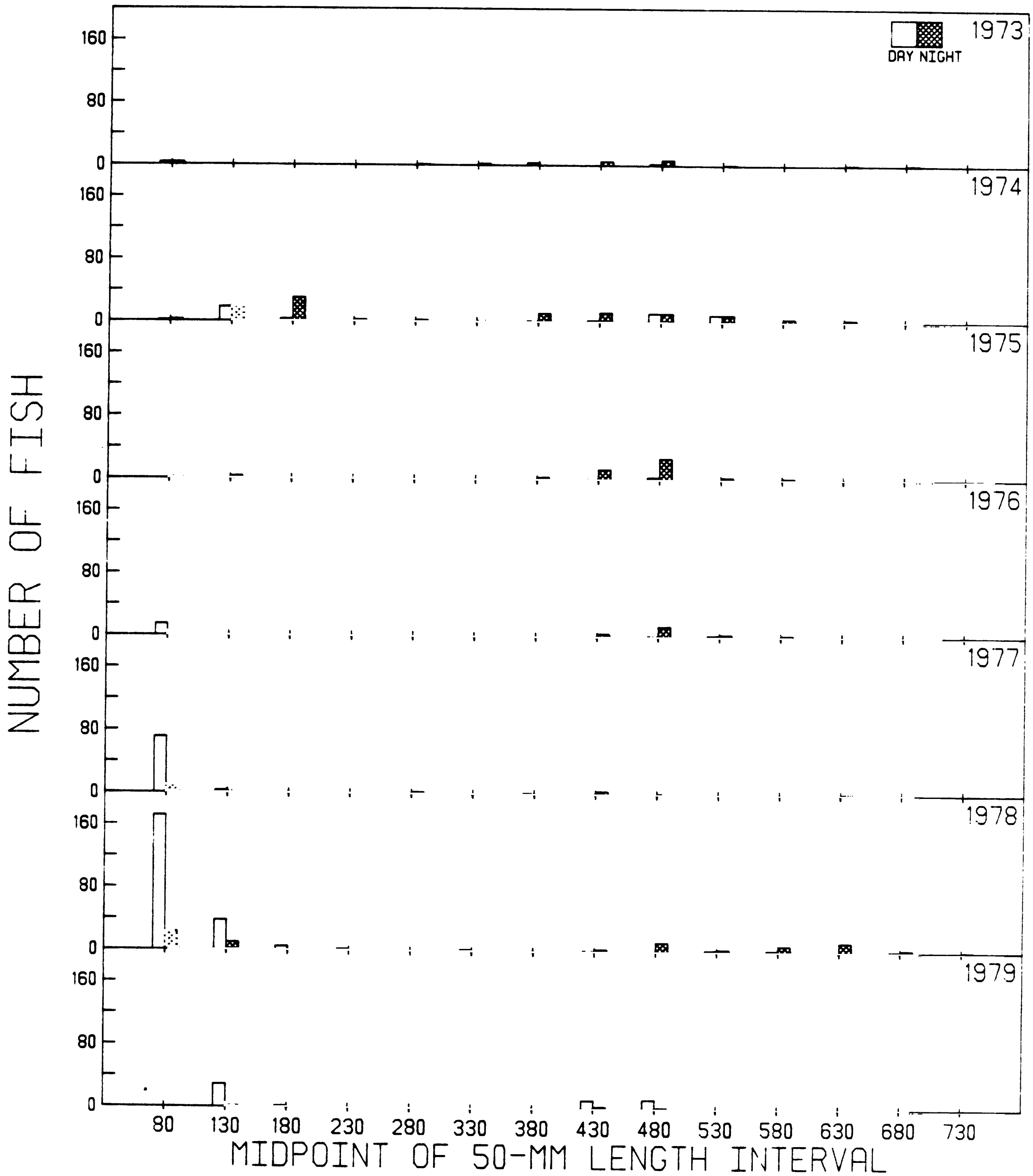


Fig. 82. Length-frequency histograms of coho salmon caught by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

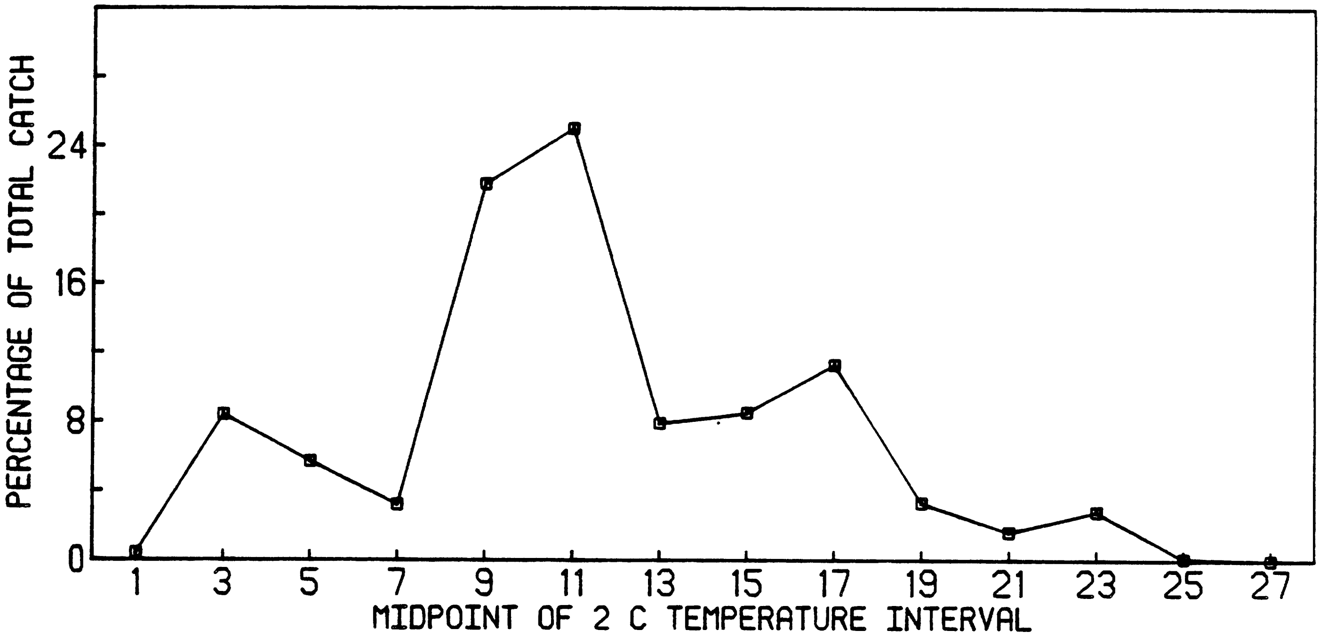


Fig. 83. Percentage of the combined total standard series catch of coho salmon collected during 1973-1979 from various temperatures in Cook Plant study areas, southeastern Lake Michigan.

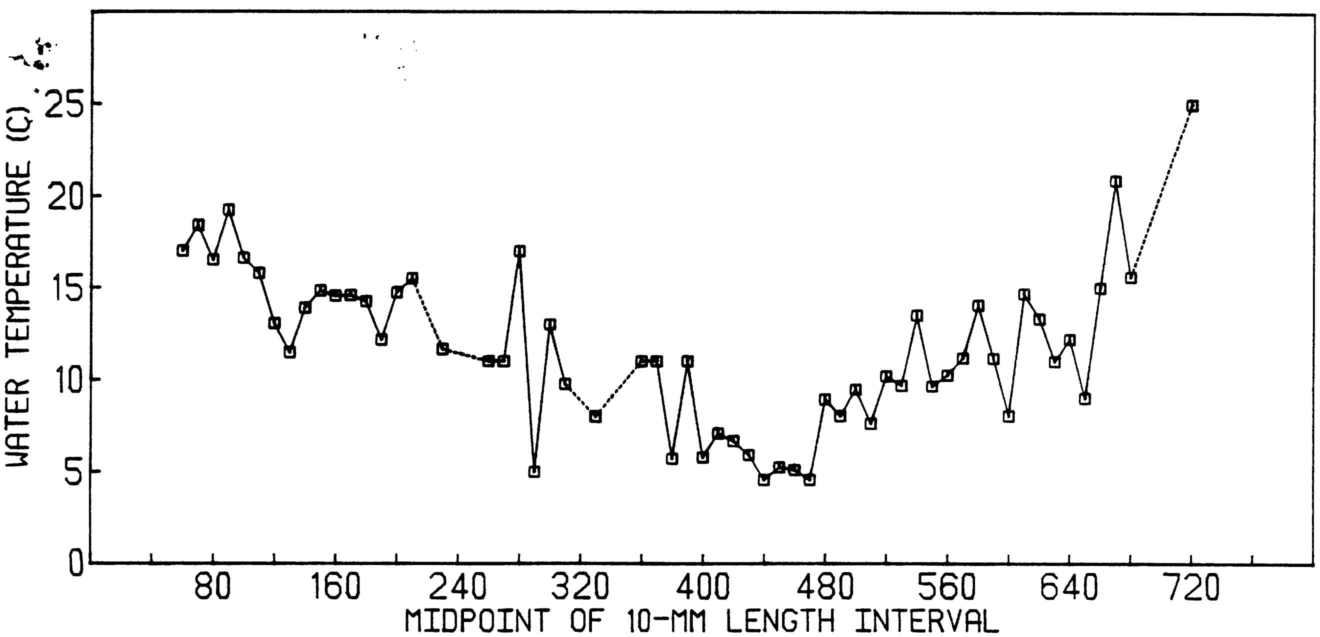


Fig. 84. Mean temperature at which various sizes of coho salmon were caught during 1973-1979 by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan.

Common Carp

Operational Effects--

Common carp were frequently caught by seining and gillnetting from 1973 to 1979, but few were trawled. Total catch of carp from standard series fishing ranged from 27 in 1973 and 1974 to 92 in 1977. Carp were usually collected throughout the sampling year with no abundance peak occurring in any one season (Fig. 85). The total yearly catches from Warren Dunes and Cook areas were nearly equal during preoperational years. However, during operational years the total number of carp caught at the Cook plant increased greatly over preoperational catches and over concurrent Warren Dunes catches (Fig. 86). Because most carp were caught in gill nets every year, these data were subjected to nonparametric analyses.

Analyses of gill net data showed that the 1973 and 1974 catches were significantly smaller than catches during all subsequent operational years (Table 53). Although more carp were caught in 1979 than previous years, there was no significant difference in catch between years of one-unit and two-unit operation (1975-1978 vs. 1979). The Kruskal-Wallis test did indicate a significant difference in catch among areas during 1975-1979. Warren Dunes catches were significantly smaller than those from the Cook areas. Catches at north and south Cook stations were not significantly different.

These analyses show that as a result of plant operation carp have been attracted to the Cook area. Significant increases in catch during operational years at Cook but not at Warren Dunes provide evidence of this plant effect. The thermal plume and its associated currents at Cook are the most probable reason for increased catches. Slightly elevated water temperatures near Cook provide a favorable habitat for this species. Pitt et al. (1956) reported the

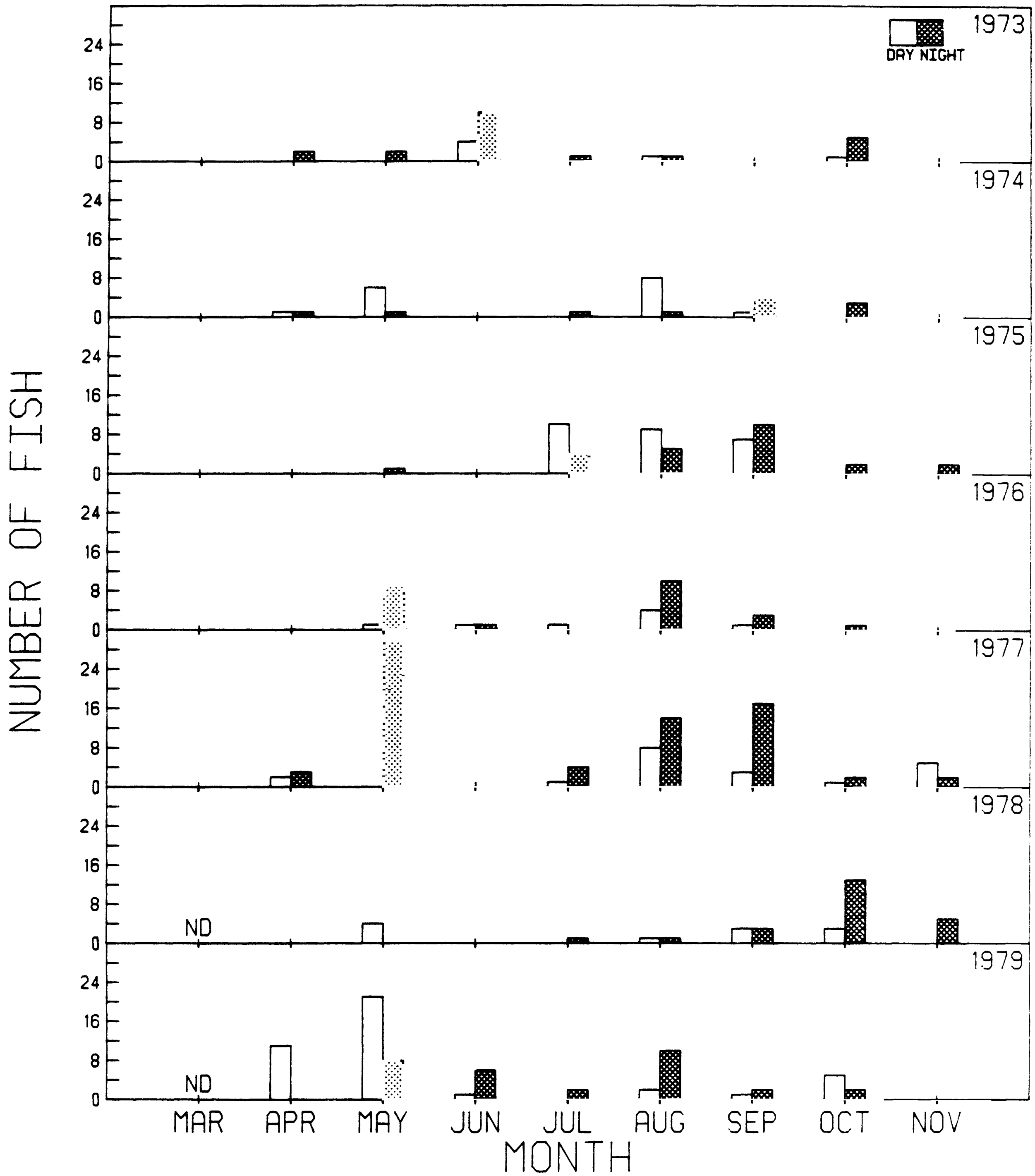


Fig. 85. Number of common carp caught by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years. ND = no data.

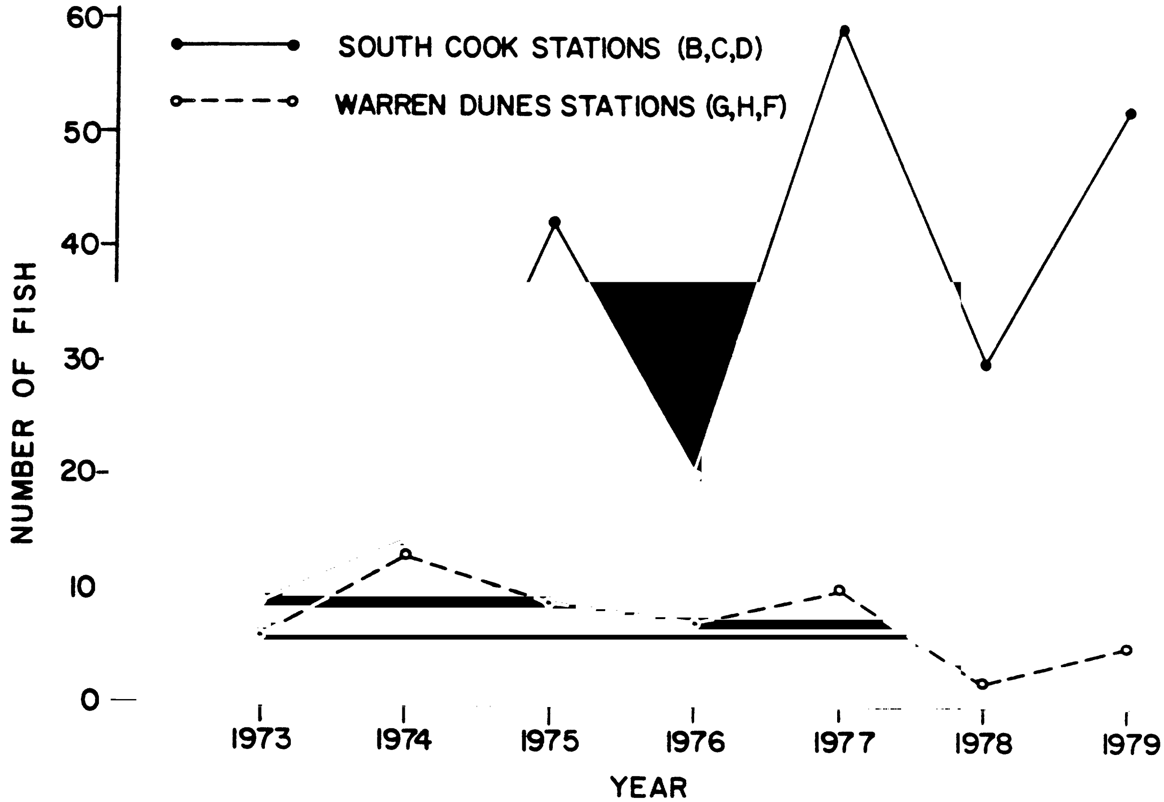


Fig. 86. Number of common carp caught by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

Table 53. Results of the Kruskal-Wallis test (nonparametric ANOVA) applied to 1973-1979 common carp gill net catch data from Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df	H statistic	Attained significance
Station (G, H, C, D, R, Q)	5	36.0510	0.0000*
Area (Warren Dunes, south Cook, north Cook)	2	28.3150	0.0000*
(Warren Dunes, Cook Plant)	1	27.0640	0.0000*
Year (1973-1979)	6	18.6130	0.0049*
(1973-74, 1975-79)	1	12.5650	0.0004*
(1973-74, 1975-78, 1979)	2	14.6910	0.0006*
(1973-74, 1975-77, 1978-79)	2	14.5770	0.0007*
(1973-74, 1975-77, 1978, 1979)	3	16.1480	0.0011*
Depth (6 m, 9 m)	1	5.0238	0.0250*
Time (day, night)	1	0.1999	0.6548

* Significant (P <0.1).

final temperature preferenda for carp as 32.0°C. Areas near Cook's discharge structures are often warmer than other areas. Although presence of carp has been considered unfavorable in many waters (Gerking 1950, Ricker and Gottschalk 1940), their increased abundance has not had any detectable effect on other fish species in the Cook Plant vicinity.

Biological Data--

Carp were distributed in the catch from the beach to at least 9 m. However, overall, twice as many carp were gillnetted at 6 m than at 9 m (Table 54). This significant difference (P = 0.0250) resulted from especially large catches at the north and south Cook 6-m stations (C and R). Although gill net catches of carp at Warren Dunes were small, catches at 6-m stations (eight fish) were more nearly equal to catches at 9-m stations (six fish). Occurrence of large numbers of carp at 6-m Cook stations is the result of an attraction to the warm thermal plume at the discharge.

Carp typically inhabit warm, eutrophic environments. Although available habitats in the Cook Plant vicinity are not ideal carp habitats, the thermal discharge provides a more suitable environment for carp than surrounding waters. Carp were caught over a range of temperatures, but the greatest catches occurred in waters from 15 to 23°C (Fig. 87). In addition, there was no apparent relationship between carp size and temperature selection (Fig. 88).

Analysis of day vs. night differences in the carp gill net catch showed nocturnal catches accounted for just over half (59.9%) of the total catch (Table 54). Hence, no well-defined activity period was indicated from the catch of this gear. However, diel differences were more pronounced in the seine catch (73.9% during night), suggesting inshore movements may accompany

Table 54. Number of common carp gillnetted at standard series stations and stations R and Q in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years. ND = no data.

		6-m stations			9-m stations		
		Cook Plant		Warren Dunes	Cook Plant		Warren Dunes
		North	South		North	South	
Year	Time period	R	C	G	Q	D	H
1973	Day	ND	1	0	ND	1	0
	Night	ND	5	0	ND	0	0
1974	Day	ND	0	0	ND	5	2
	Night	ND	3	1	ND	2	0
1975	Day	6	7	2	8	13	1
	Night	27	8	0	10	11	1
1976	Day	3	0	2	3	2	1
	Night	6	8	0	1	5	0
1977	Day	8	12	1	3	4	1
	Night	11	19	0	4	14	0
1978	Day	5	9	0	0	0	0
	Night	13	18	0	2	1	0
1979	Day	5	29	1	1	1	0
	Night	8	11	1	5	9	1

nocturnal activity or that carp are better able to avoid the seine during the day (Table 55).

Carp with ripe and spent gonads were caught from May through September every year (Table 56), indicating a rather extended spawning season. Very few immature individuals were caught, and the majority of carp caught every year were between 500 and 700 mm (Fig. 89). The absence of juveniles in standard series catches may reflect preference for a habitat not sampled by our gear. Carp did spawn in the study area because larvae were collected during all operational years.

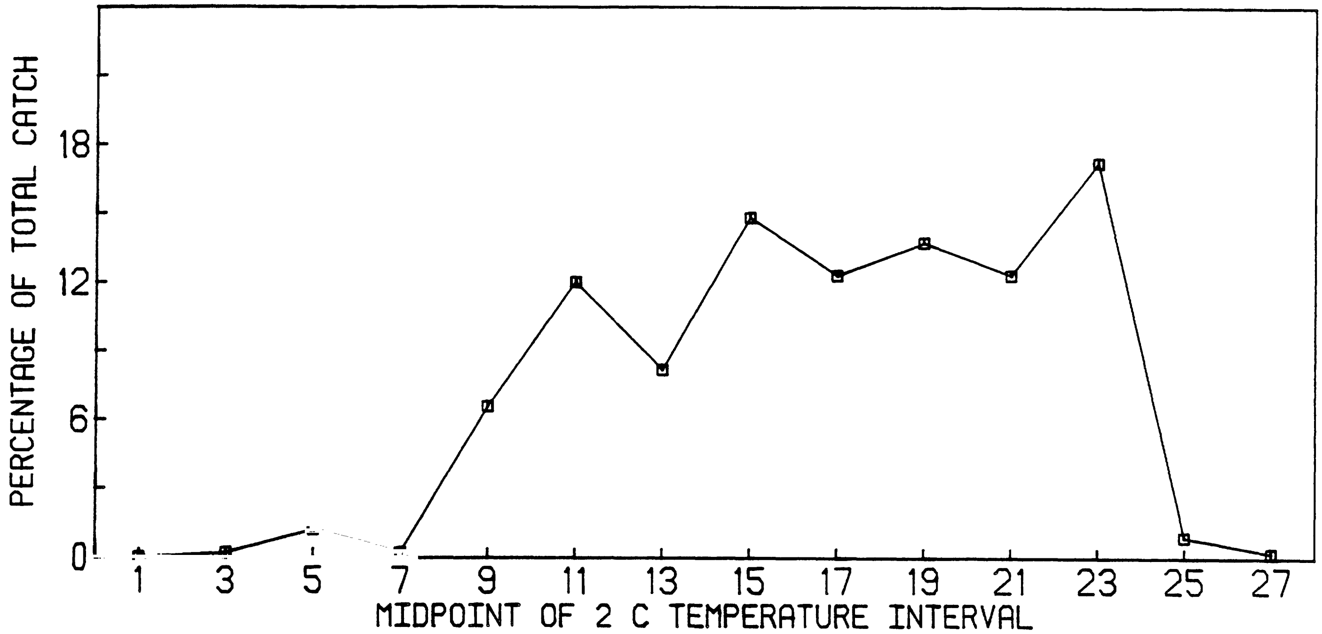


Fig. 87. Percentage of the combined total standard series catch of common carp collected during 1973-1979 from various temperatures in Cook Plant study areas, southeastern Lake Michigan.

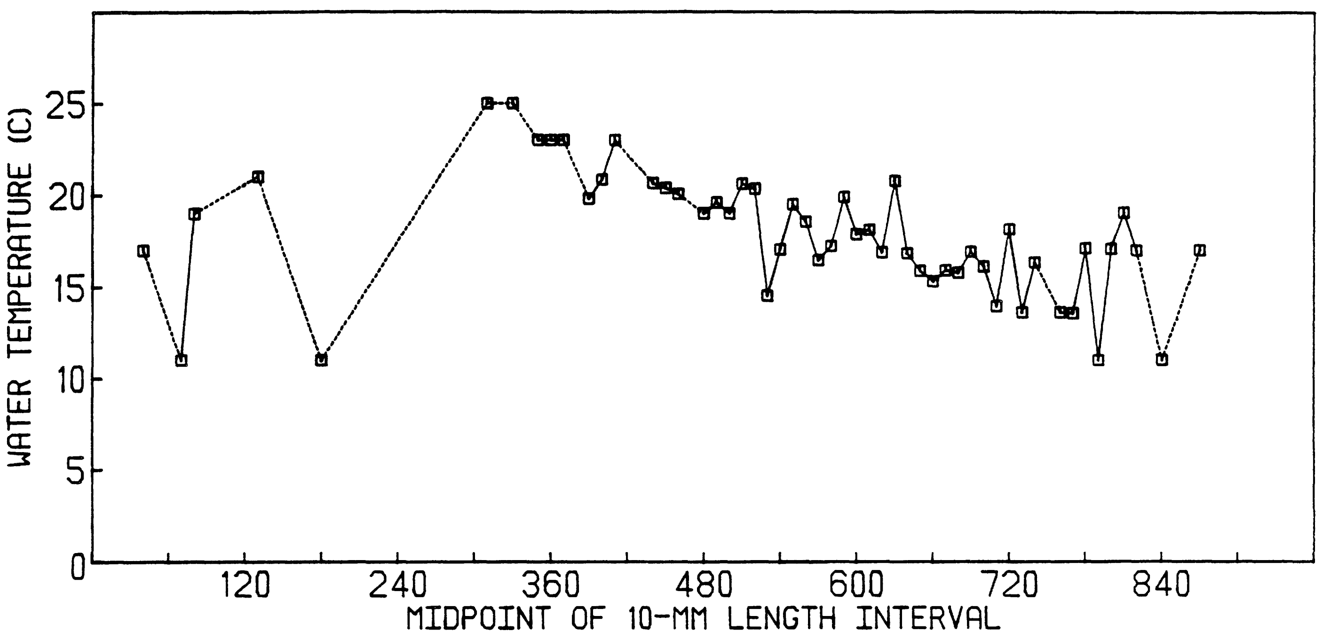


Fig. 88. Mean temperature at which various sizes of common carp were caught during 1973-1979 by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan.

Table 55. Number of common carp seined at standard series stations in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

		Cook Plant stations		Warren Dunes station
		North	South	
Year	Time period	A	B	F
1973	Day	4	0	0
	Night	8	2	6
1974	Day	0	2	6
	Night	1	1	2
1975	Day	0	0	1
	Night	0	1	2
1976	Day	1	1	0
	Night	4	3	3
1977	Day	0	0	2
	Night	23	10	6
1978	Day	2	0	0
	Night	0	2	1
1979	Day	10	0	0
	Night	4	1	2

Table 56. Number of ripe and spent common carp caught by standard series trawling, gillnetting, and seining in Cook Plant study areas, southeastern Lake Michigan, 1973-1979. F = female, M = male, ND = no data.

Year	Sex	Gonad condition	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	F	Ripe	0	0	0	1	0	0	0	3	0	0
		Spent	0	0	0	0	0	0	0	0	0	0
	M	Ripe	0	2	2	10	0	0	0	1	0	0
		Spent	0	0	0	0	0	0	0	0	0	0
1974	F	Ripe	0	0	0	0	0	0	0	0	0	0
		Spent	0	0	0	0	1	0	0	0	0	0
	M	Ripe	0	0	0	0	0	0	0	0	0	0
		Spent	0	0	0	0	0	0	0	0	0	0
1975	F	Ripe	0	0	0	0	6	5	6	0	1	0
		Spent	0	0	0	0	0	2	0	0	0	0
	M	Ripe	0	0	0	0	1	0	3	0	0	1
		Spent	0	0	1	0	2	4	0	0	0	0
1976	F	Ripe	0	0	4	0	0	2	0	0	0	ND
		Spent	0	0	0	0	0	1	0	0	0	ND
	M	Ripe	0	0	3	0	0	7	0	0	0	ND
		Spent	0	0	1	2	1	1	0	0	0	ND
1977	F	Ripe	0	1	15	0	1	11	7	1	4	0
		Spent	0	0	0	0	0	0	0	0	0	0
	M	Ripe	0	3	0	0	4	5	12	0	3	0
		Spent	0	0	15	0	0	1	1	0	0	0
1978	F	Ripe	ND	0	4	0	0	0	1	6	0	ND
		Spent	ND	0	0	0	0	0	0	0	0	ND
	M	Ripe	ND	0	0	0	0	0	0	3	0	ND
		Spent	ND	0	0	0	0	0	0	0	0	ND
1979	F	Ripe	ND	3	7	3	1	2	2	0	0	ND
		Spent	ND	0	1	1	0	0	0	0	0	ND
	M	Ripe	ND	4	17	1	1	4	0	0	0	ND
		Spent	ND	0	0	0	0	1	0	0	0	ND

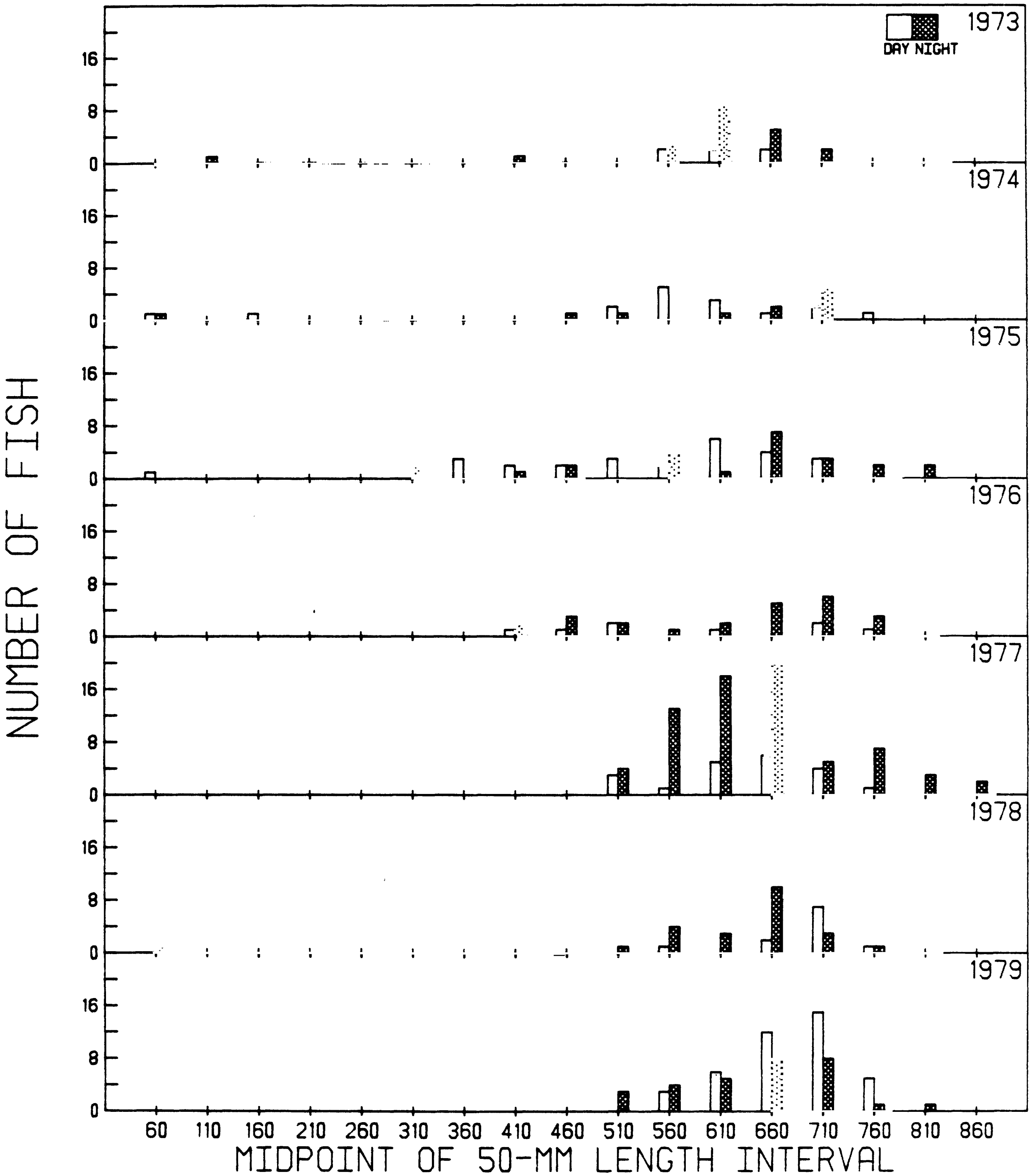


Fig. 89. Length-frequency histograms of common carp caught by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

Gizzard Shad

Operational Effects--

Gizzard shad were collected every year during 1973-1979, but represented less than 0.3% of total annual catches. From 1973 to 1979, trawls, gill nets, and seines accounted for 4.1, 58.4, and 37.4% of gizzard shad, respectively, in the standard series catch. Mostly YOY and yearlings were seined, while both juveniles and adults were gillnetted. Most gizzard shad were collected from August to November (Fig. 90). Gill net data were analyzed by nonparametric tests for possible effect of plant operation; seine and trawl catches were too small and sporadic to test statistically.

Catches in 1973 and 1974 were significantly different (Table 57). Except for 1976, gill net catches increased steadily during 1973-1979. The catch during preoperational years was significantly smaller than the catch during operational years, suggesting possible plant effects. No gizzard shad were gillnetted in 1973 and only 30 in 1974 (Table 58). Catches ranged from 45 fish in 1976 to 136 in 1979.

Catches between stations and between depths were similar. Area, however, was a significant source of variation. The catch at the north Cook area was significantly larger than at Warren Dunes (Table 57). Catches at north and south Cook were similar. Mean annual catch was 67 fish at north Cook, 57 at south Cook, and 24 at Warren Dunes. Attraction of gizzard shad to discharged warm water was implicated as the main cause of larger gizzard shad catches at Cook. This species is attracted to warm water flowing out of industrial plants (Miller 1960, Bodola 1966). Rock riprap near the intake and discharge structures may also be responsible for concentration of gizzard shad at Cook.

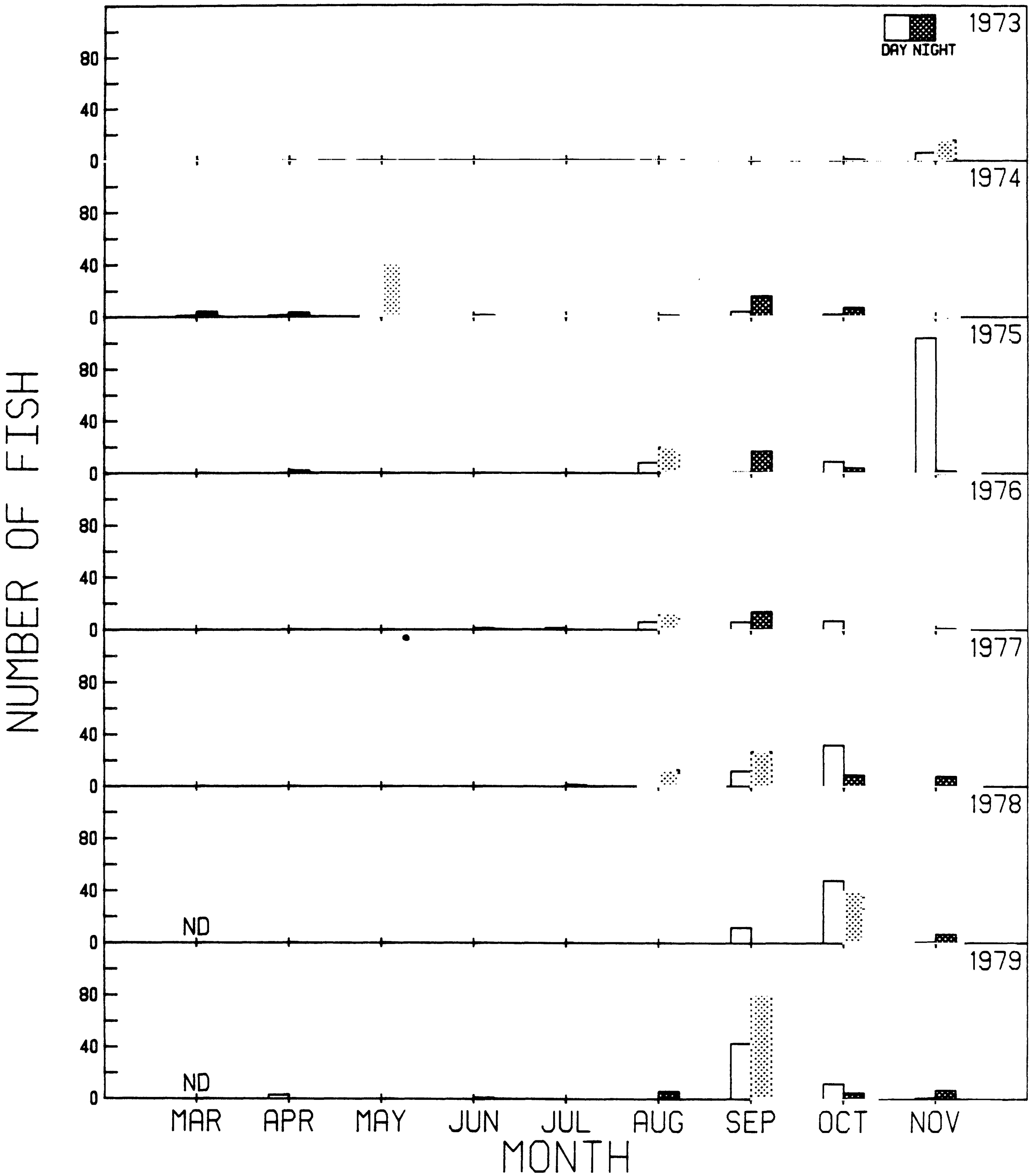


Fig. 90. Number of gizzard shad caught by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years. ND = no data.

Table 57. Results of the Kruskal-Wallis test (nonparametric ANOVA) applied to 1973-1979 gizzard shad gill net catch data from Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df	H statistic	Attained significance
Station (G, H, C, D, R, Q)	5	6.4369	0.2660
Area (Warren Dunes, south Cook, north Cook)	2	4.8367	0.0891*
(Warren Dunes, Cook Plant)	1	2.5539	0.1100
Year (1973-1979)	6	12.7950	0.0464*
(1973-74, 1975-79)	1	6.9605	0.0083*
(1973-74, 1975-78, 1979)	2	7.2815	0.0262*
(1973-74, 1975-77, 1978-79)	2	12.2680	0.0022*
(1973-74, 1975-77, 1978, 1979)	3	7.3809	0.0607*
Depth (6 m, 9 m)	1	1.2564	0.2623
Time (day, night)	1	2.2939	0.1299

* Significant (P <0.1).

Table 58. Number of gizzard shad gillnetted at standard series stations and stations R and Q in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years. ND = no data.

		6-m stations			9-m stations		
		Cook Plant			Cook Plant		
Year	Time period	North	South	Warren Dunes	North	South	Warren Dunes
		R	C	G	Q	D	H
1973	Day	ND	0	0	ND	0	0
	Night	ND	0	0	ND	0	0
1974	Day	ND	0	3	ND	1	2
	Night	ND	6	10	ND	3	5
1975	Day	4	0	7	2	0	2
	Night	11	12	11	7	11	3
1976	Day	8	8	2	17	8	1
	Night	23	5	9	13	6	6
1977	Day	0	5	2	1	3	4
	Night	20	21	4	52	13	3
1978	Day	52	61	0	1	0	0
	Night	21	13	18	27	13	2
1979	Day	10	8	15	1	19	3
	Night	27	25	22	39	37	7

Biological Data--

Gizzard shad collected ranged from 70 to 720 mm. Most 70- to 200-mm fish were probably yearlings. Since gizzard spawn in spring and summer, some smaller individuals collected in the fall may be YOY. Catches of yearlings and YOY in the study area fluctuated considerably during 1973-1979, with large catches in 1974 and 1975 and small catches in 1976 and 1979 (Fig. 91). Relatively greater abundance in 1974 and 1975 may be due to strong year classes. Large catches of immature gizzard shad in 1974 and 1975, however, resulted from a single seine haul, suggesting that fluctuations of catches may be caused by patchiness of gizzard shad distribution.

Most larger gizzard shad were 320 to 470 mm (Fig. 91). Based on length-age data of gizzard shad from Lake Erie (Bodola 1966), fish in this size range were 2 to 4 years old. Gizzard shad in this group were not caught in 1973. From 1974 to 1979, catches of these fish appeared to show fewer fluctuations than those in the immature group. Largest catches of adult gizzard shad occurred in 1979. Gizzard shad 220 to 300 mm and those larger than 470 mm were scarce in the study area.

Gizzard shad spawn in spring and summer (Scott and Crossman 1973) in lakes or rivers (Miller 1960). In Lake Erie spawning takes place during June and July (Bodola 1966). We did not collect any gizzard shad in spawning condition, nor did we collect their larvae. During summer adults had spent or underdeveloped gonads (Table 59). These data suggest that gizzard shad spawn outside the study area, possibly in tributary rivers. High concentrations of gizzard shad YOY were observed in the Grand River, 125 km north of the Cook Plant.

Catches of gizzard shad were generally low from April to July during 1973-1979, except during 1974 when a substantial number of immature gizzard

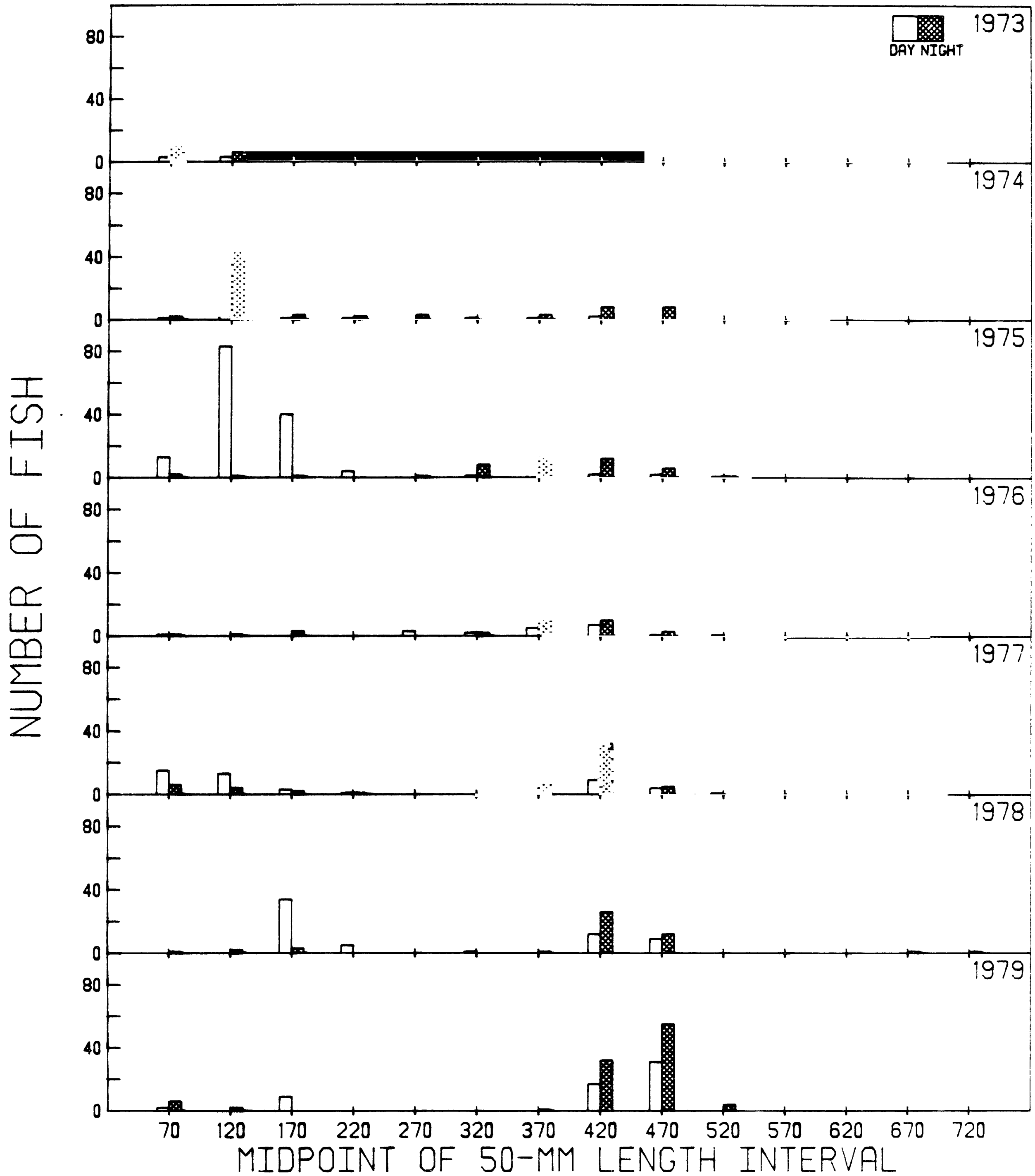


Fig. 91. Length-frequency histograms of gizzard shad caught by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

Table 59. Number of ripe and spent gizzard shad caught by standard series trawling, gillnetting, and seining in Cook Plant study areas, southeastern Lake Michigan, 1973-1979. F = female, M = male, ND = no data.

Year	Sex	Gonad condition	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	F	Ripe	0	0	0	0	0	0	0	0	0	0
		Spent	0	0	0	0	0	0	0	0	0	0
	M	Ripe	0	0	0	0	0	0	0	0	0	0
		Spent	0	0	0	0	0	0	0	0	0	0
1974	F	Ripe	0	0	0	0	0	0	0	0	0	0
		Spent	0	0	0	0	0	0	1	2	0	0
	M	Ripe	0	0	0	0	0	0	0	0	0	0
		Spent	0	0	0	0	0	0	0	0	0	0
1975	F	Ripe	0	0	0	0	0	0	0	0	0	0
		Spent	0	0	0	0	0	4	0	0	0	0
	M	Ripe	0	0	0	0	0	0	0	0	0	0
		Spent	0	0	0	0	0	9	0	0	0	0
1976	F	Ripe	0	0	0	0	0	0	0	0	0	ND
		Spent	0	0	0	0	0	10	0	0	0	ND
	M	Ripe	0	0	0	0	0	0	0	0	0	ND
		Spent	0	0	0	0	0	1	0	0	0	ND
1977	F	Ripe	0	0	0	0	0	0	0	0	0	0
		Spent	0	0	0	0	0	0	0	0	0	0
	M	Ripe	0	0	0	0	0	0	0	0	0	0
		Spent	0	0	0	0	0	0	0	0	0	0
1978	F	Ripe	ND	0	0	0	0	0	0	0	0	ND
		Spent	ND	0	0	0	0	0	0	0	0	ND
	M	Ripe	ND	0	0	0	0	0	0	3	0	ND
		Spent	ND	0	0	0	0	0	0	0	0	ND
1979	F	Ripe	ND	0	0	0	0	0	0	0	0	ND
		Spent	ND	0	0	0	0	0	22	0	0	ND
	M	Ripe	ND	0	0	0	0	0	0	0	0	ND
		Spent	ND	0	0	0	0	0	3	0	0	ND

shad were collected (Fig. 90). Scarcity of adult gizzard shad in spring and early summer may be related to spawning activities outside the study area. Most gizzard shad were collected from August to November. Both adults and yearlings occurred during the summer. In the fall, most gizzard shad collected were yearlings and YOY.

Low numbers of adults collected in seines suggested that larger gizzard shad were able to escape seines or remained in deeper water outside the beach zone. Yearlings and YOY were most commonly caught in seines. In western Lake Erie, Bodola (1966) found most young gizzard shad in shallow areas along the shores. In our study area, yearlings also inhabited 6- and 9-m depths since a substantial number were collected in gill nets.

Gizzard shad prefer warm water. Reutter and Herdendorf (1974) reported a temperature preferendum of 20.5°C for Lake Erie gizzard shad. In the Wabash River in Indiana, gizzard shad prefer temperatures from 23.5 to 30°C (Gammon 1973). In our study area, gizzard shad occurred in relatively cool water, most being caught at 13 to 20°C (Fig. 92). The apparent bimodal pattern of temperature preference in Figure 92 was due to large catches at 15°C during spring and fall and another peak catch at 19°C during late summer. Young gizzard shad less than 300 mm were generally found in colder water than larger fish (Fig. 93). Gammon (1973), however, found small gizzard shad of 175 mm average length tolerate warmer water (up to 34°C) than adults.

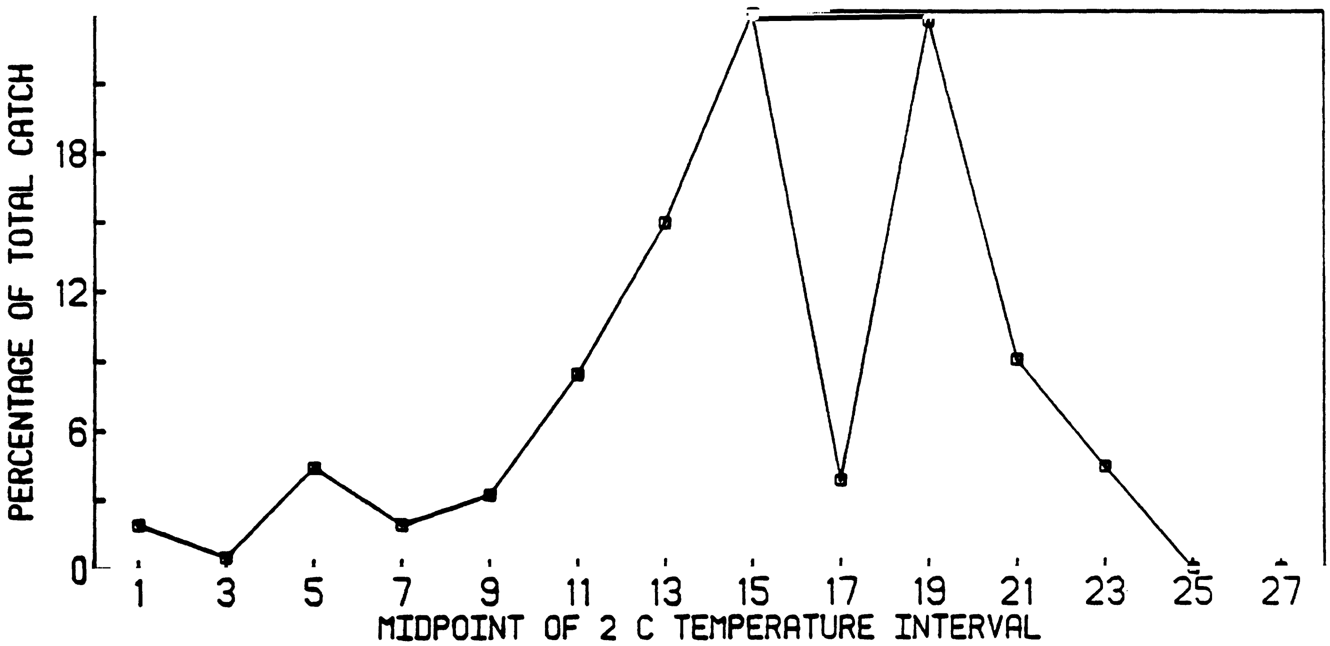


Fig. 92. Percentage of the combined total standard series catch of gizzard **shad collected during 1973-1979 from** various temperatures in Cook Plant study **areas, southeastern Lake Michigan.**

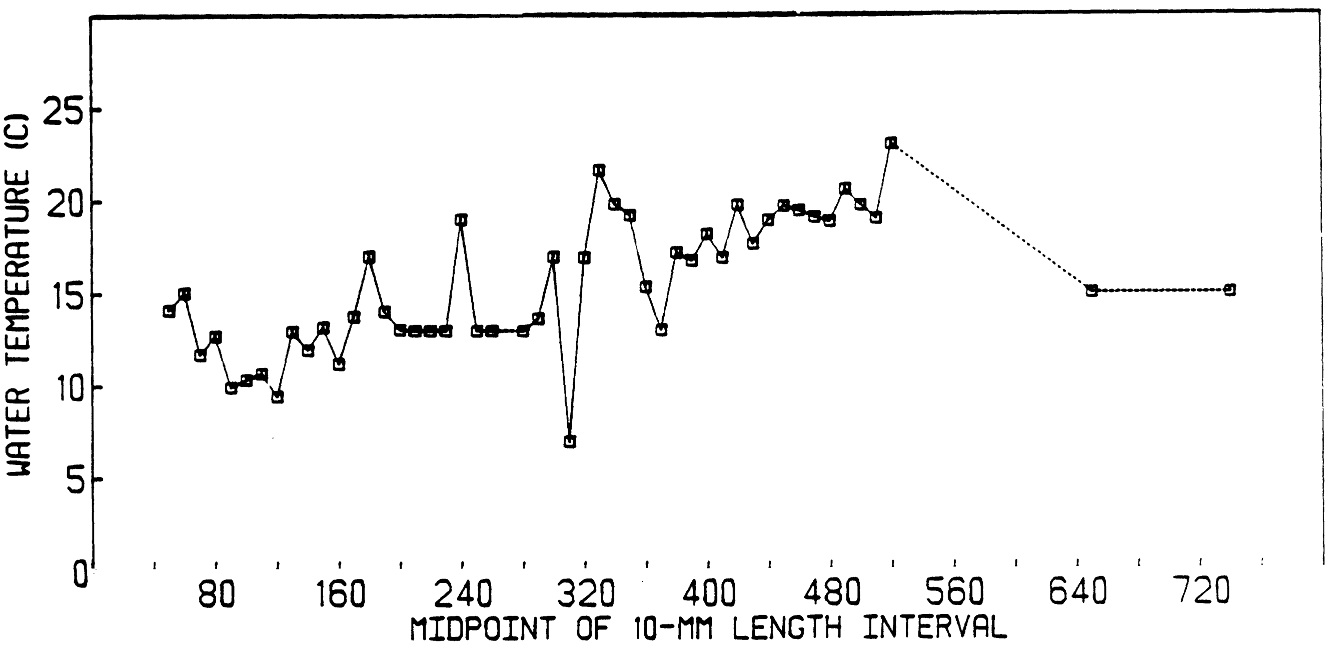


Fig. 93. **Mean temperature** at which various sizes of gizzard shad were caught during 1973-1979 by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan.

Johnny Darter

Operational Effects--

Johnny darter was the sixth to eighth most abundant species collected each year from 1973 to 1979. Yearly catches ranged from a low of 142 fish in 1975 to a high of 423 fish in 1977 and averaged 284 fish. Most (93%) darters were trawled, while none were gillnetted; an average of 20 fish per year were seined.

Results of the Kruskal-Wallis test applied to trawl data showed significant differences among or between station, area, and year catches (Table 60). However, these findings did not establish any detrimental plant effects. The difference between the catch in preoperational years 1973 and 1974 was not significantly different from the catch in operational years 1975-1979 (Table 60). Also, the significant difference in area catches resulted from a significantly larger catch at south Cook than at Warren Dunes. Part of the cause for the area difference was a large catch at station C (6 m, south Cook) which was significantly greater than the catch at station G (6 m, Warren Dunes). Larger catches at station C than at station G also occurred in preoperational years (Table 61). The catches at the 9-m stations were not significantly different. These station-area differences are probably related to the plant's riprap. Divers found more darters on the riprap than on the sandy areas elsewhere in the study area (Dorr 1974, Dorr and Miller 1975, Dorr and Jude 1980). This attraction to the riprap may have increased abundance of darters at station C, although no sampling occurred before riprap placement in 1972 and 1973. Total yearly catches at station R (6 m, north Cook) were also greater than at the Warren Dunes 6-m station (Table 61), presumably because of the riprap attraction.

Table 60. Results of the Kruskal-Wallis test (nonparametric ANOVA) applied to 1973-1979 johnny darter trawl catch data from Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df	H statistic	Attained significance
Station (G, H, C, D, R)	4	21.0840	0.0003*
Area (Warren Dunes, south Cook, north Cook)	2	5.0252	0.0811*
(Warren Dunes, Cook Plant)	1	3.1453	0.0761*
Year (1973-1979)	6	27.1030	0.0001*
(1973-74, 1975-79)	1	1.7485	0.1861
(1973-74, 1975-78, 1979)	2	6.6223	0.0365*
(1973-74, 1975-77, 1978-79)	2	5.4568	0.0653*
(1973-74, 1975-77, 1978, 1979)	3	8.3885	0.0386*
Replicate (1st haul, 2nd haul)	1	0.2983	0.5850
Depth (6 m, 9 m)	1	3.0882	0.0789*
Time (day, night)	1	120.8700	0.0000*

* Significant ($P < 0.1$).

Attraction of johnny darters to riprap at the plant's intakes and the resulting impingement and mortality of this species is a plant effect. However, field catches have not shown a population decline at Cook stations. Conceivably, impingement mortality is being compensated by increased recruitment resulting from the riprap providing a spawning substrate. Johnny darters did spawn on the riprap (Dorr and Jude 1980).

Addition of Unit 2 operation in 1979 did not appear to affect the darter population although the 1979 total catch (233 fish) was below the 7-year average. The Kruskal-Wallis test showed the 1979 catch was significantly different from catches in preoperational years and in operational years 1975-1978 (Table 60). However, multiple range testing showed the 1979 catch was not significantly different from the catches in 1975 and 1973.

Table 61. Number of johnny darters trawled at standard series stations and station R in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years. ND = no data.

		6-m stations			9-m stations	
		Cook Plant				
		North	South	Warren Dunes	Cook Plant	Warren Dunes
Year	Time period	R	C	G	D	H
1973	Day	ND	15	6	21	11
	Night	ND	72	25	22	29
1974	Day	ND	11	19	10	21
	Night	ND	101	34	50	43
1975	Day	3	9	4	7	16
	Night	34	38	11	18	25
1976	Day	23	30	13	32	8
	Night	85	62	20	72	59
1977	Day	10	19	14	11	29
	Night	93	97	33	77	97
1978	Day	8	18	15	14	25
	Night	76	87	52	72	97
1979	Day	0	10	1	7	6
	Night	35	36	26	47	42

Biological Data--

Johnny darter catch data showed an abundance peak in spring and another increase in the fall (Fig. 94). This pattern, which was typical of many fish species, resulted from seasonal inshore-offshore movements and recruitment of YOY. Adults and yearlings began moving inshore in April, and abundance peaked in May or June when spawning occurred. Presence of fish with ripe gonads in July indicated that some spawning may also have occurred into July (Table 62). Johnny darters did spawn in the study area because larvae were collected most

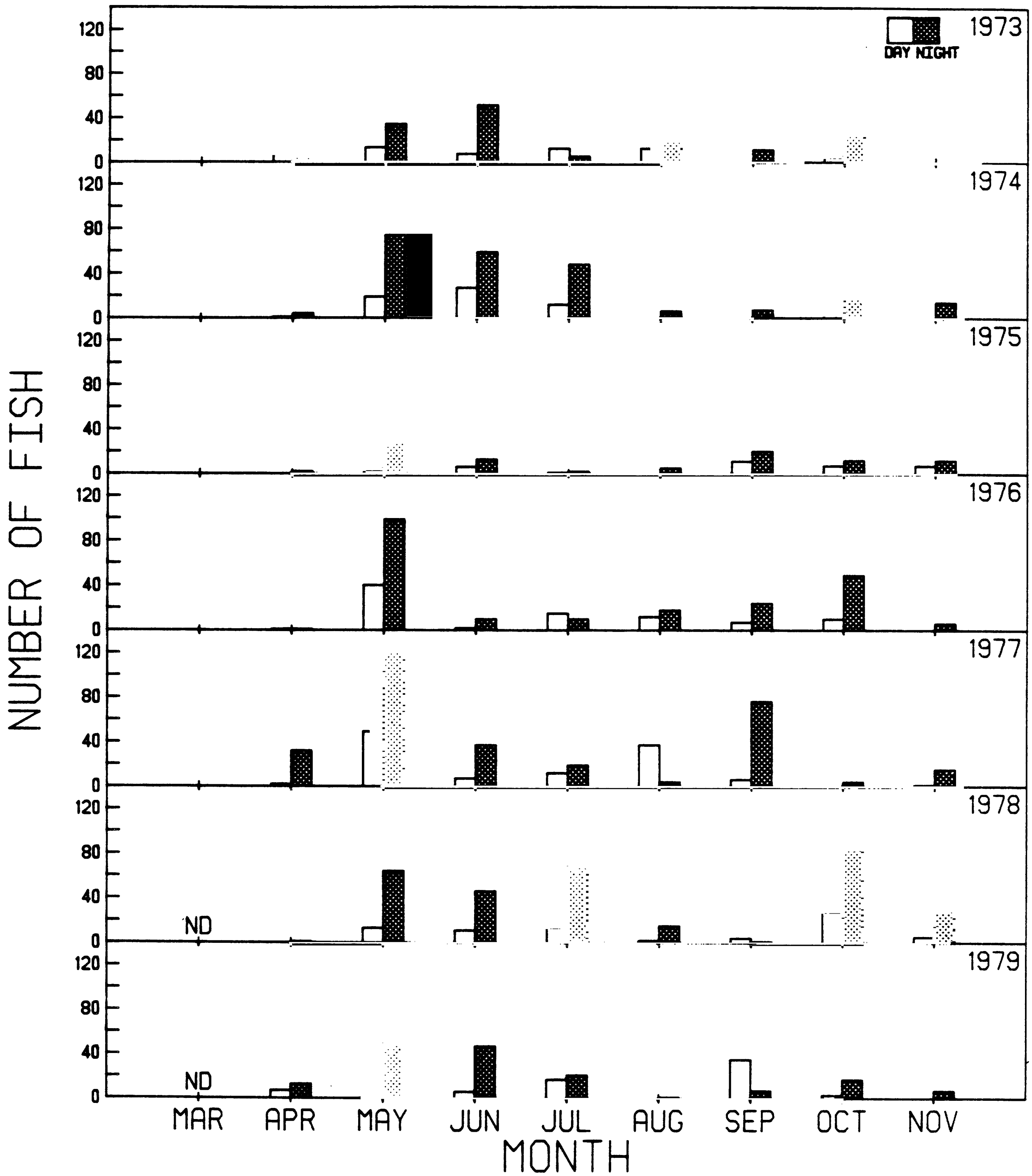


Fig. 94. Number of johnny darters caught by standard series seining and trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years. ND = no data.

Table 62. Number of ripe or spent johnny darters caught by standard series trawling, gillnetting, and seining in Cook Plant study areas, southeastern Lake Michigan, 1973-1979. F = female, M = male, ND = no data.

Year	Sex	Gonad condition	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	F	Ripe	0	4	17	13	1	0	0	0	0	0
		Spent	0	0	0	5	4	8	2	0	0	0
	M	Ripe	0	2	4	4	1	0	0	0	0	0
		Spent	0	0	0	3	3	2	1	0	0	0
1974	F	Ripe	0	0	35	22	6	0	0	0	0	0
		Spent	0	0	4	1	1	0	0	0	0	0
	M	Ripe	0	0	14	1	0	0	0	0	1	0
		Spent	0	0	0	1	0	0	0	0	0	0
1975	F	Ripe	0	0	6	5	0	0	2	0	0	0
		Spent	0	0	0	2	0	0	2	2	0	0
	M	Ripe	0	0	1	0	0	0	0	0	0	0
		Spent	0	0	0	0	0	0	0	1	0	0
1976	F	Ripe	0	0	30	1	4	0	1	0	0	ND
		Spent	0	0	1	2	2	1	0	0	0	ND
	M	Ripe	0	0	11	1	4	0	0	0	0	ND
		Spent	0	0	1	0	1	0	0	0	0	ND
1977	F	Ripe	0	3	53	1	1	0	0	0	1	0
		Spent	0	0	2	1	2	1	0	0	0	0
	M	Ripe	0	3	24	2	1	0	0	0	0	0
		Spent	0	0	3	1	0	0	0	0	0	0
1978	F	Ripe	ND	0	11	5	2	0	0	2	0	ND
		Spent	ND	0	0	0	0	0	0	0	0	ND
	M	Ripe	ND	0	4	1	0	0	0	0	0	ND
		Spent	ND	0	0	0	0	0	0	0	0	ND
1979	F	Ripe	ND	0	1	10	3	0	0	0	0	ND
		Spent	ND	0	0	0	0	0	0	0	0	ND
	M	Ripe	ND	0	0	0	0	0	0	0	0	ND
		Spent	ND	0	0	0	0	0	0	0	0	ND

years (Jude et al. 1979), and divers found eggs on the plant's riprap (Dorr and Jude 1980). After spawning most adults moved offshore resulting in small summer catches. Johnny darters collected near the Campbell Plant on eastern Lake Michigan showed a similar movement pattern and spawning period (Jude et al. 1981). At a more northerly Lake Michigan location (Ludington, Michigan), johnny darters moved inshore and spawned approximately 1 month later than in our study area (Brazo and Liston 1979). The fall abundance increase in our study area resulted from recruitment of YOY to the sampling gear. In addition, catch data also indicated an inshore movement of some yearlings and adults coinciding with fall breakup of the thermocline.

Johnny darters were more vulnerable to sampling at night than during the day (Fig. 94). The difference between day and night catches was statistically significant (Table 60). Trawl catches showed that some darters moved shoreward from 9 m and presumably deeper water to 6 m at night, thus increasing night catches. However, daylight net avoidance probably contributed to the diel differences. Darters occasionally moved into the beach zone, but they were never commonly seined.

Except for 1975, most darters collected each year were in the 40- to 60-mm length intervals (Fig. 95). Most johnny darters collected near Ludington, Michigan, were also in these length intervals (Brazo and Liston 1979). Published data on length-at-age for johnny darters (Raney and Lachner 1943, Karr 1963, Brazo and Liston 1979) indicate most darters we collected were 1-, 2-, and 3-year olds. Larger fish in the 70- and 80-mm intervals were possibly 4-years old. The largest darter found in the study area, an 87-mm fish impinged during June 1975, was considerably larger than the largest fish (76 mm) reported in the literature (Trautman 1981). Young-of-the-year, first

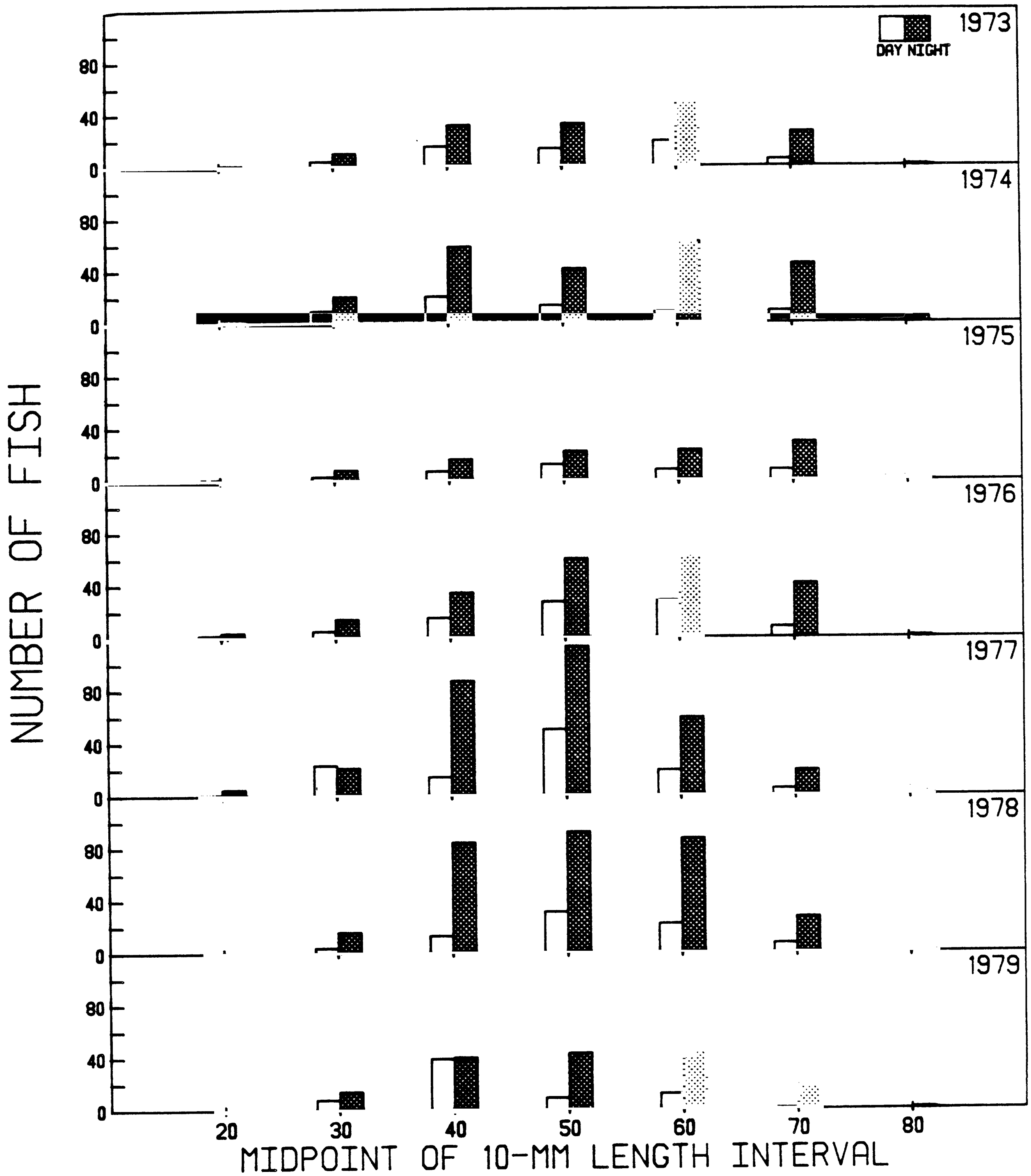


Fig. 95. Length-frequency histograms of johnny darters caught by standard series seining and trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

collected in July or August at a modal length of 20 mm, usually grew to modal lengths of 40 or 50 mm in October and November. Brazo and Liston (1979) first collected YOY near Ludington in August at 20-25 mm.

Johnny darters were collected over a wide temperature range, although few were found at the highest temperatures sampled (Fig. 96). Younger (smaller) fish were usually collected in warmer water than older fish (Fig. 97), presumably because young fish prefer warmer water. This characteristic was also noted for alewife, rainbow smelt, spottail shiner, yellow perch, white sucker, and longnose sucker.

Lake Trout

Operational Effects--

From 37 to 286 lake trout were collected each year in the study areas; mean catch was 149. Few lake trout (0 to 10 yearly) were collected by trawl or seine. Bottom gill nets were by far the most effective gear for capturing lake trout, thus fluctuations in abundance were most strongly reflected in gill net catches. Lake trout comprised an average of 0.13% of the total standard series catch and 1.94% of the gill net catch.

Lake trout catch fluctuated widely from year to year, with 1975 and 1976 catches low and the 1978 catch high relative to other years of the study. The Kruskal-Wallis test applied to gill net data showed significant differences among catches for 1973-1979 (Table 63). Nemenyi's test showed 1978 was significantly higher in rank than years 1973-1976; this grouping could not be attributed to plant operation. Although Kruskal-Wallis results taken alone appear to indicate differences between preoperational and operational years

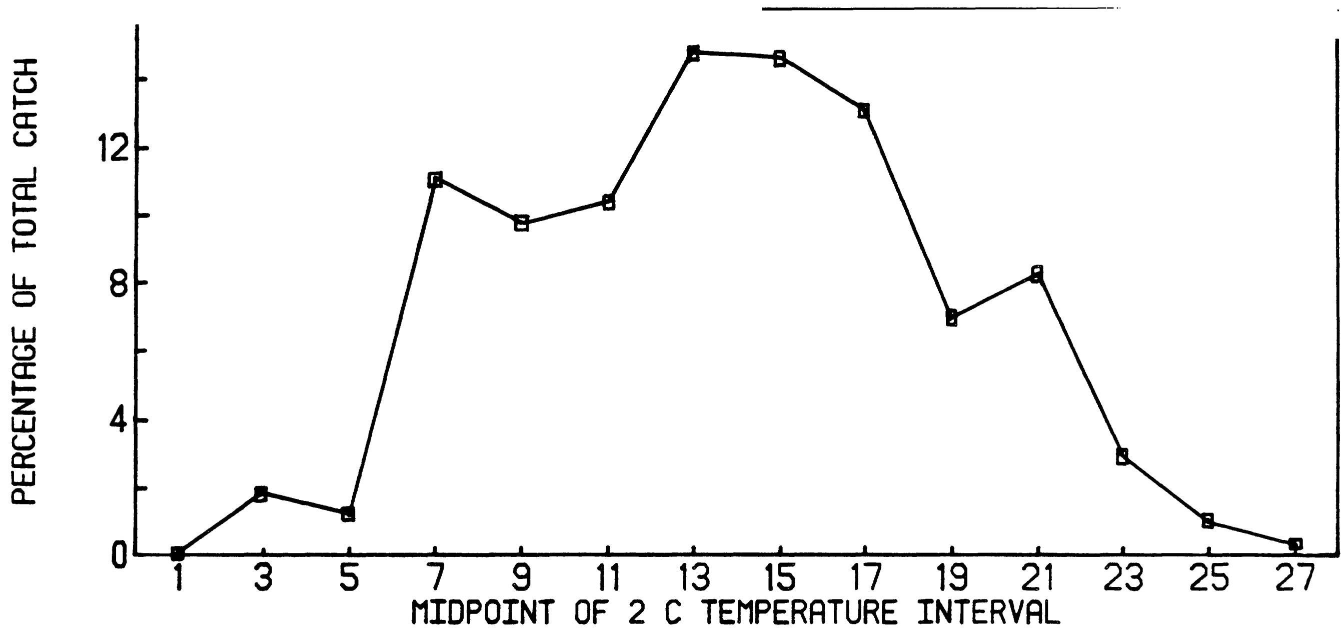


Fig. 96. Percentage of the combined total standard series catch of johnny darters collected during 1973-1979 from various temperatures in Cook Plant study areas, southeastern Lake Michigan.

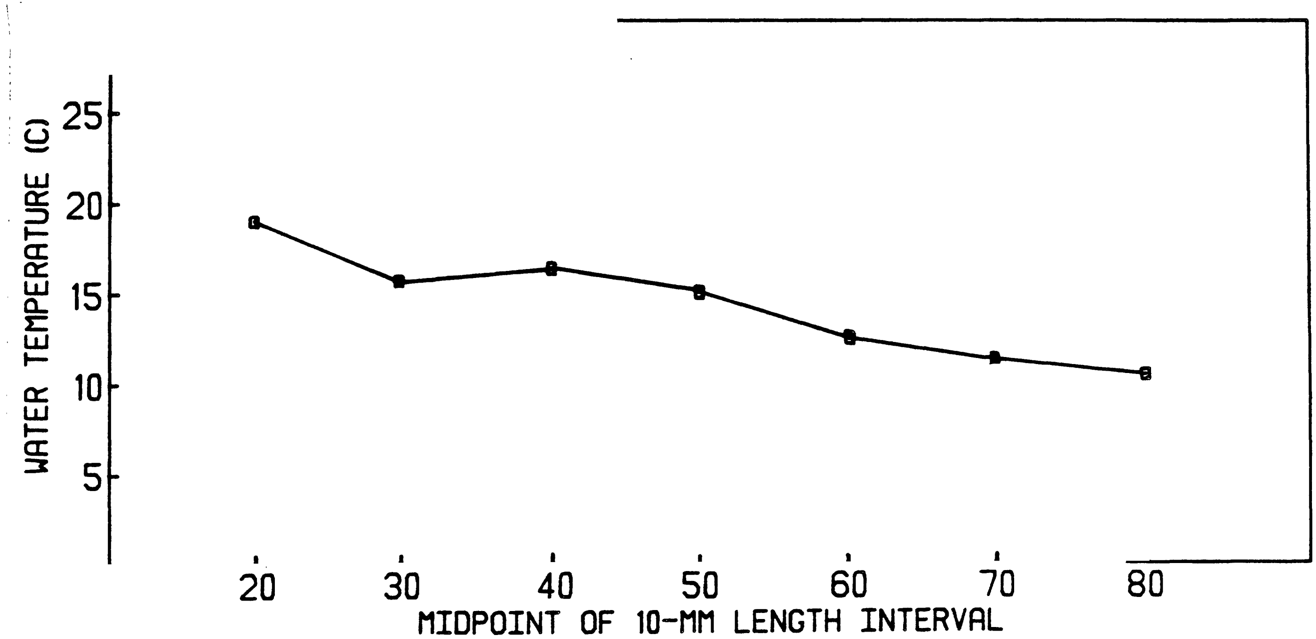


Fig. 97. Mean temperature at which various sizes of johnny darters were caught during 1973-1979 by standard series seining and trawling in Cook Plant study areas, southeastern Lake Michigan.

Table 63. Results of the Kruskal-Wallis test (nonparametric ANOVA) applied to 1973-1979 lake trout gill net catch data from Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df	H statistic	Attained significance
Station (G, H, C, D, R, Q)	5	1.5958	0.9018
Area (Warren Dunes, south Cook, north Cook)	2	1.5022	0.4718
(Warren Dunes, Cook Plant)	1	0.7357	0.3911
Year (1973-1979)	6	49.2470	0.0000*
(1973-74, 1975-79)	1	4.8185	0.0282*
(1973-74, 1975-78, 1979)	2	5.2170	0.0736*
(1973-74, 1975-77, 1978-79)	2	14.6410	0.0007*
(1973-74, 1975-77, 1978, 1979)	3	38.8170	0.0000*
Depth (6 m, 9 m)	1	0.0371	0.8474
Time (day, night)	1	48.7800	0.0000*

* Significant (P <0.1).

(Table 63), examination of each year's catch in detail reveals reasons for these differences other than plant operation. In most years, peak catch occurred in November (Fig. 98); however, due to inclement weather, gill nets were not set in November or during the night in October 1976, thus accounting for the very low 1976 catch. Lake trout prefer water temperatures around 10°C (Scott and Crossman 1973), and their distribution is often strongly influenced by temperature. November 1975 gillnetting was earlier in the month than usual, and water temperatures were warmer (12-13.5°C at fishing depth) than any other November gillnetting period, 1973-1979. Furthermore, numerous lake trout eggs washed onto the beach a week after the November gill netting when inshore water temperatures were 10.5-11.5°C (Jude et al. 1979), thus November 1975 gillnetting undoubtedly occurred before the spawning peak. Much of the large 1978 catch occurred in September, during an upwelling of hypolimnetic

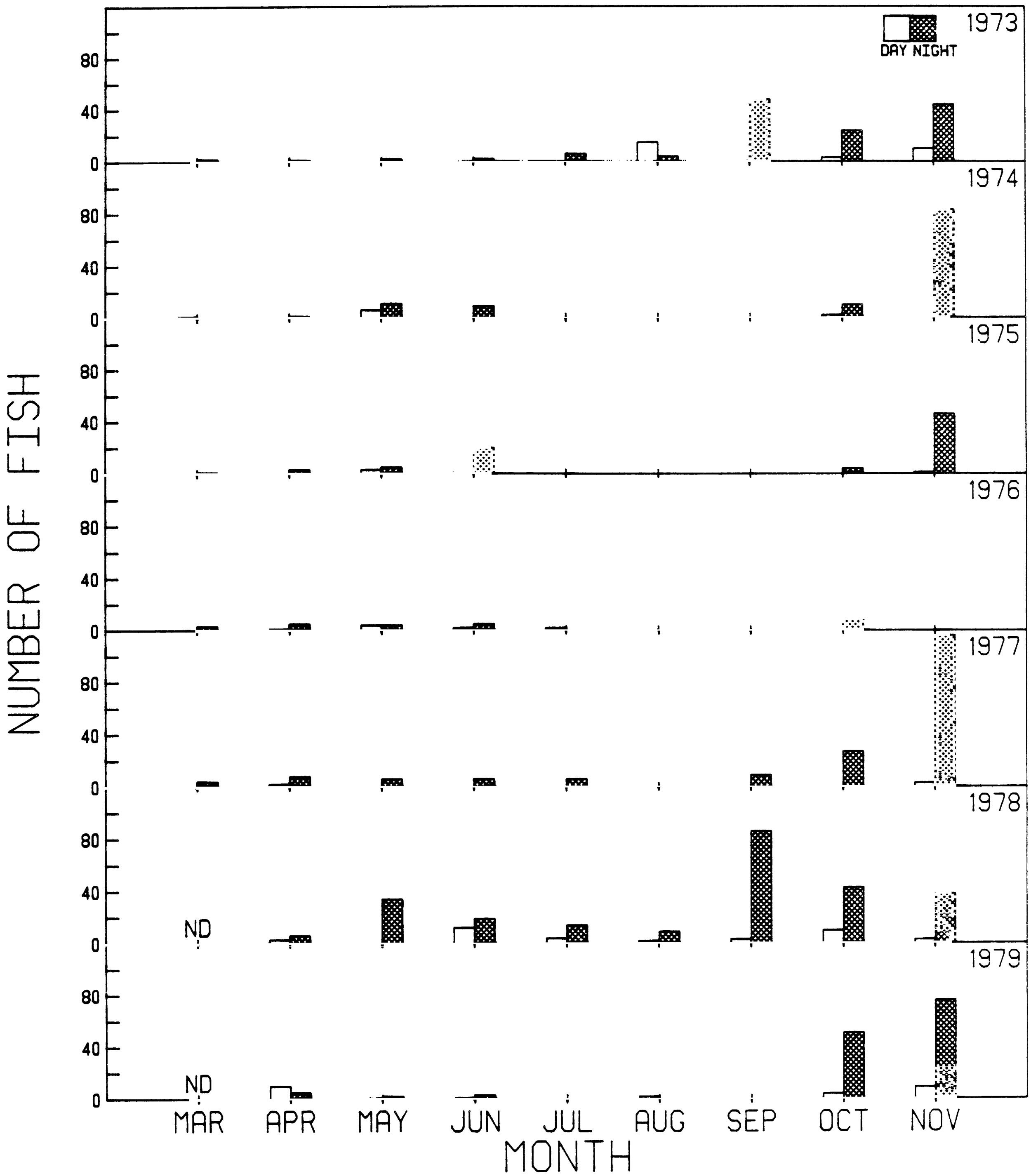


Fig. 98. Number of lake trout caught by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years. ND = no data.

water which brought many lake trout inshore. Also, summer 1978 water temperatures were low, 6-15°C at gillnetting depths, permitting more lake trout to stay inshore than in most years. For the above reasons, it appears that year-to-year variation in lake trout abundance is not the result of plant effects.

Although the Kruskal-Wallis test showed no significant difference between Warren Dunes and Cook Plant areas, the many zero catches reduced the power of the analysis. Examination of the data by station shows that there were usually more lake trout at Cook stations than at Warren Dunes stations (Table 64). Over all 7 years, we collected a mean of 46 lake trout at south Cook stations C (6 m), D (9 m), R (6 m), and Q (9 m), compared with a mean catch of 26 lake trout at Warren Dunes stations G (6 m) and H (9 m). The most likely reason for this difference is attraction to the plant's riprap for spawning. Investigators at Ludington (210 km north of Cook) found more lake trout at a station with irregular, rocky substrate than at sand substrate stations, regardless of plant location (Brazo and Liston 1979). However, at the Campbell Plant 110 km north of Cook, Jude et al. (1981) found greater lake trout abundance at stations near the riprap compared with reference stations only for those years when construction of the new intake and discharge was occurring, possibly because net avoidance was reduced by turbidity or food organisms were more available. Lake trout may reside in a thermal plume for short periods of time (Spigarelli 1975), presumably to feed on forage fish attracted to warm water, but our data provide no evidence of trout concentrating in the plume. Overall, field data indicate no adverse effect of the plant.

Table 64. Number of lake trout gillnetted at standard series stations and stations R and Q in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years. ND = no data.

		6-m stations			9-m stations		
		Cook Plant		Warren Dunes	Cook Plant		Warren Dunes
		North	South		North	South	
Year	Time Period	R	C	G	Q	D	H
1973	Day	ND	7	4	ND	3	14
	Night	ND	64	19	ND	38	9
1974	Day	ND	3	1	ND	4	2
	Night	ND	56	24	ND	28	2
1975	Day	1	1	0	0	0	1
	Night	33	42	7	14	18	9
1976	Day	4	3	0	1	1	4
	Night	15	1	3	7	8	3
1977	Day	1	0	2	2	1	2
	Night	67	56	51	38	48	26
1978	Day	3	20	5	10	10	2
	Night	65	69	47	84	74	52
1979	Day	14	5	5	11	12	3
	Night	48	28	52	49	35	12

Biological Data--

Lake trout populations in Lake Michigan declined severely during the late 1940s and early 1950s, primarily due to sea lamprey predation and subsequent failure of natural reproduction (Eschmeyer 1957). Despite control of the sea lamprey, extensive stocking has resulted in very little successful natural reproduction, which Rybicki and Keller (1976) attributed to a combination of three factors: stocked fish spawning in inappropriate areas, toxic

contaminants in eggs and larvae, and fish predation on eggs and larvae. During 1980, lake trout larvae and juveniles were collected near the Campbell Plant from the newly-deposited riprap at the plant intake and discharge (Jude et al. 1981). However, we found no evidence of successful reproduction in the Cook Plant vicinity. About 2% of the lake trout collected at Cook had no fin clips, but these fish may have missed being clipped in the hatchery, or the fins may have regenerated (all non-clipped fish were adults >500 mm).

During spring and summer, most lake trout resided in water deeper than Cook sampling stations (Fig. 98). Mature fish moved inshore in the fall, as early as September if water temperatures were low. Spawning usually took place in early November as indicated by numbers of spent fish (Table 65) and peak catches. At more northerly Lake Michigan sites, Ludington (Brazo and Liston 1979) and the Campbell Plant (Jude et al. 1982), lake trout spawned up to a month earlier, probably due to lower water temperatures. During spawning in our study areas, most lake trout were collected at 6 and 9 m, but a few were also taken in the beach zone. Usually more lake trout were collected at 6 m than at 9 m, but the difference was not statistically significant (Tables 63, 64). After spawning, lake trout moved offshore. Immature fish apparently did not move inshore with spawners, as we collected very few young fish. Occasionally we trawled lake trout 122-180 mm, probably yearlings, during summer (Fig. 99). Adult lake trout ranged up to 874 mm and 6.7 kg; most were between 605 and 755 mm (Fig. 100). Length-frequency distributions of lake trout did not change noticeably from year to year. Lengths of lake trout did not change through the season except for those collected during April 1978 and 1979 which were smaller than those collected during May through November of those years (Fig. 99).

Table 65. Number of ripe and spent lake trout caught by standard series trawling, gillnetting, and seining in Cook Plant study areas, southeastern Lake Michigan, 1973-1979. F = female, M = male, ND = no data.

Year	Sex	Gonad condition	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	F	Ripe	0	0	0	0	0	0	18	7	1	0
		Spent	1	0	0	0	0	0	0	0	6	0
	M	Ripe	0	0	0	0	0	0	9	0	4	0
		Spent	1	0	0	0	0	0	0	0	4	0
1974	F	Ripe	0	0	0	0	0	0	0	5	2	0
		Spent	0	0	0	0	0	0	0	0	19	0
	M	Ripe	0	0	0	0	0	0	0	5	8	0
		Spent	0	0	0	0	0	0	0	0	52	0
1975	F	Ripe	0	0	0	0	0	0	0	1	4	0
		Spent	0	0	0	0	0	0	0	0	15	0
	M	Ripe	0	0	0	0	0	0	0	0	2	0
		Spent	0	0	0	0	0	0	0	0	25	0
1976	F	Ripe	0	0	0	0	0	0	0	3	0	ND
		Spent	0	2	1	0	0	0	0	0	0	ND
	M	Ripe	0	0	0	0	0	0	0	4	0	ND
		Spent	0	0	0	0	0	0	0	0	0	ND
1977	F	Ripe	0	0	0	0	0	0	3	4	3	0
		Spent	0	0	1	0	0	0	0	1	16	0
	M	Ripe	0	0	1	0	0	0	6	16	0	0
		Spent	0	0	1	0	0	0	0	0	97	0
1978	F	Ripe	ND	0	0	5	6	0	27	17	1	ND
		Spent	ND	0	0	0	0	0	0	0	8	ND
	M	Ripe	ND	0	0	2	0	1	34	16	0	ND
		Spent	ND	0	0	0	0	0	0	0	15	ND
1979	F	Ripe	ND	0	0	0	0	0	0	24	4	ND
		Spent	ND	0	0	0	0	0	0	0	31	ND
	M	Ripe	ND	0	0	0	0	0	0	17	0	ND
		Spent	ND	0	0	0	0	0	0	0	47	ND

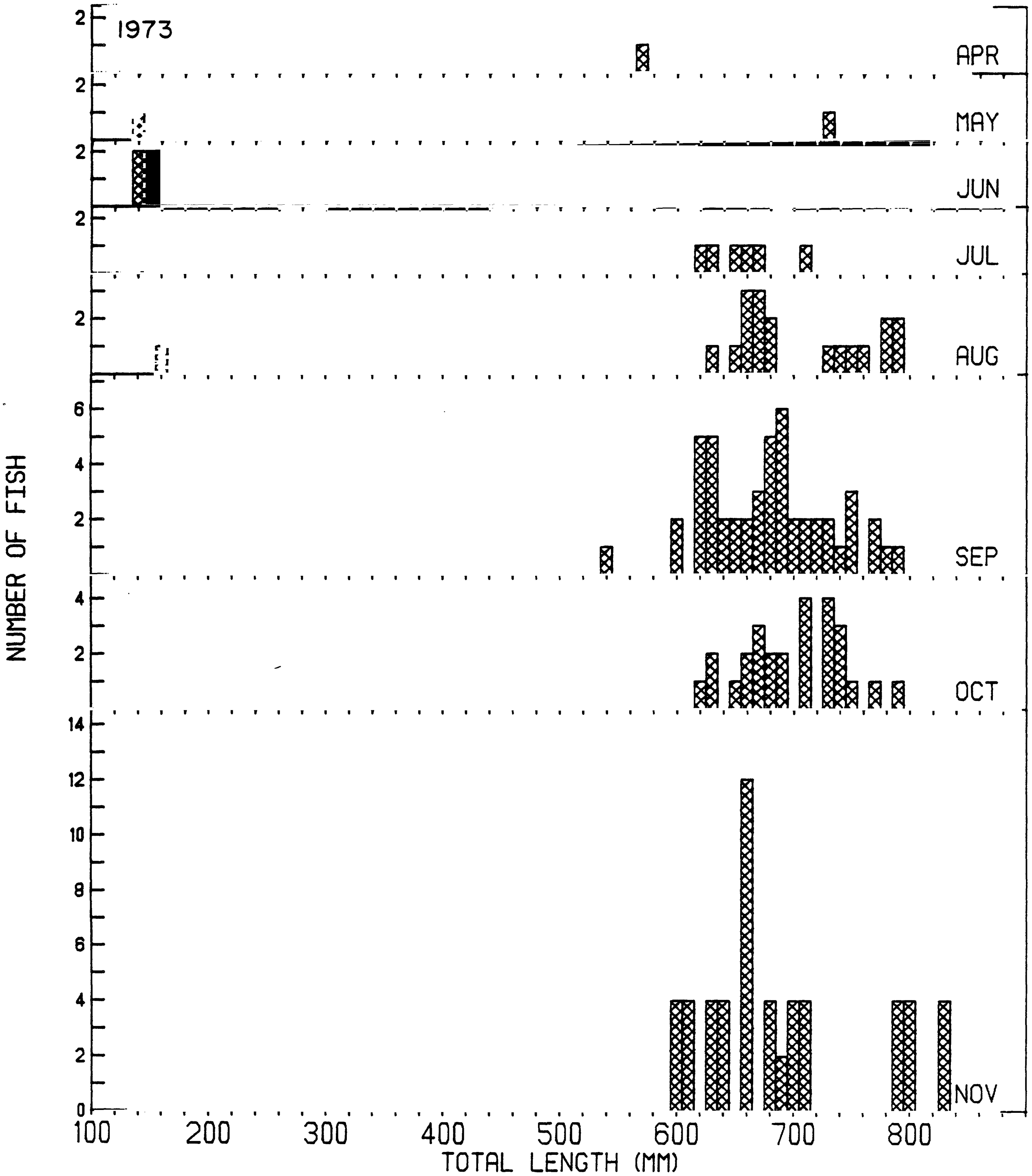
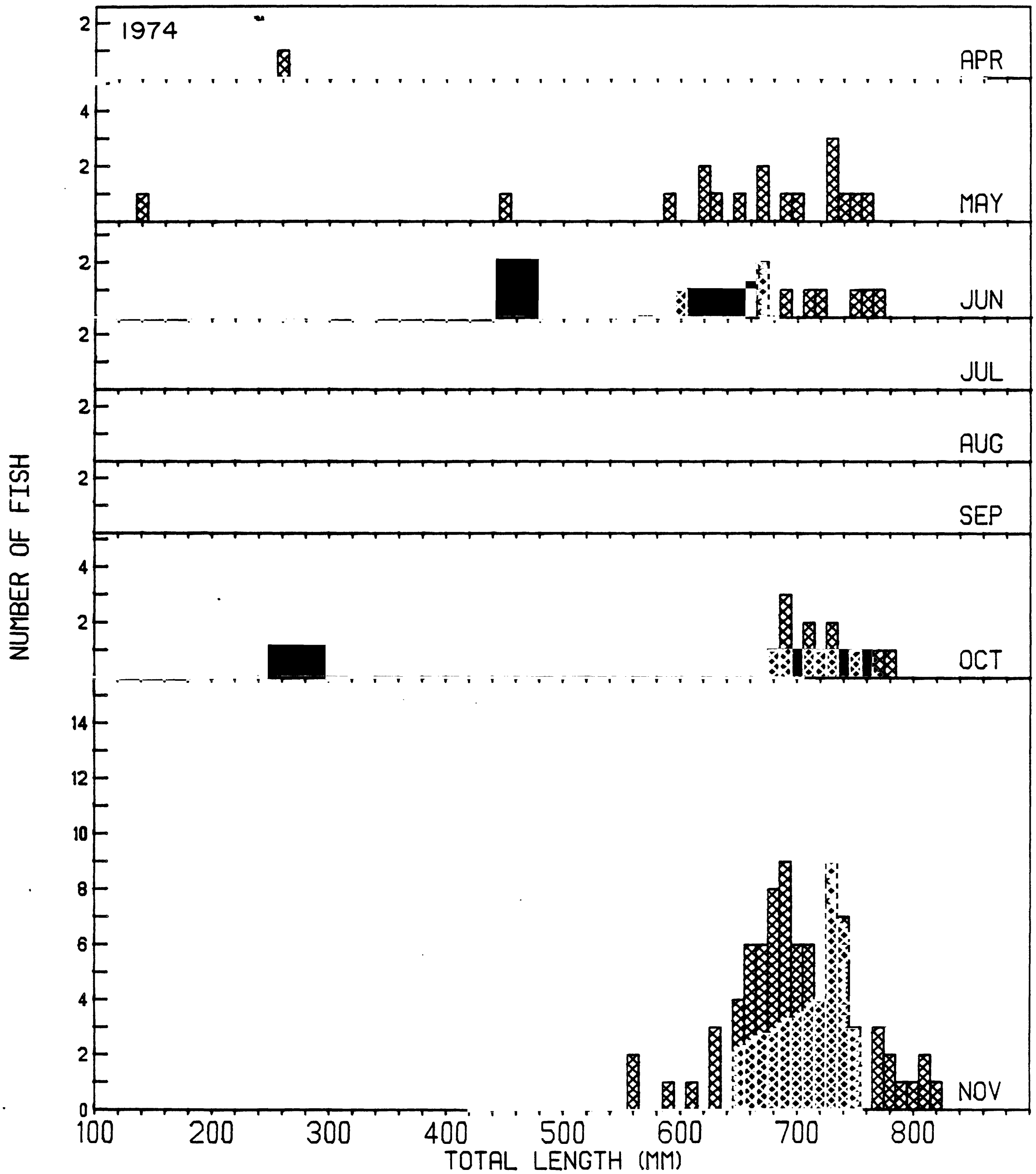


Fig. 99. Monthly length-frequency histograms of lake trout caught during 1973-1979 by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan.



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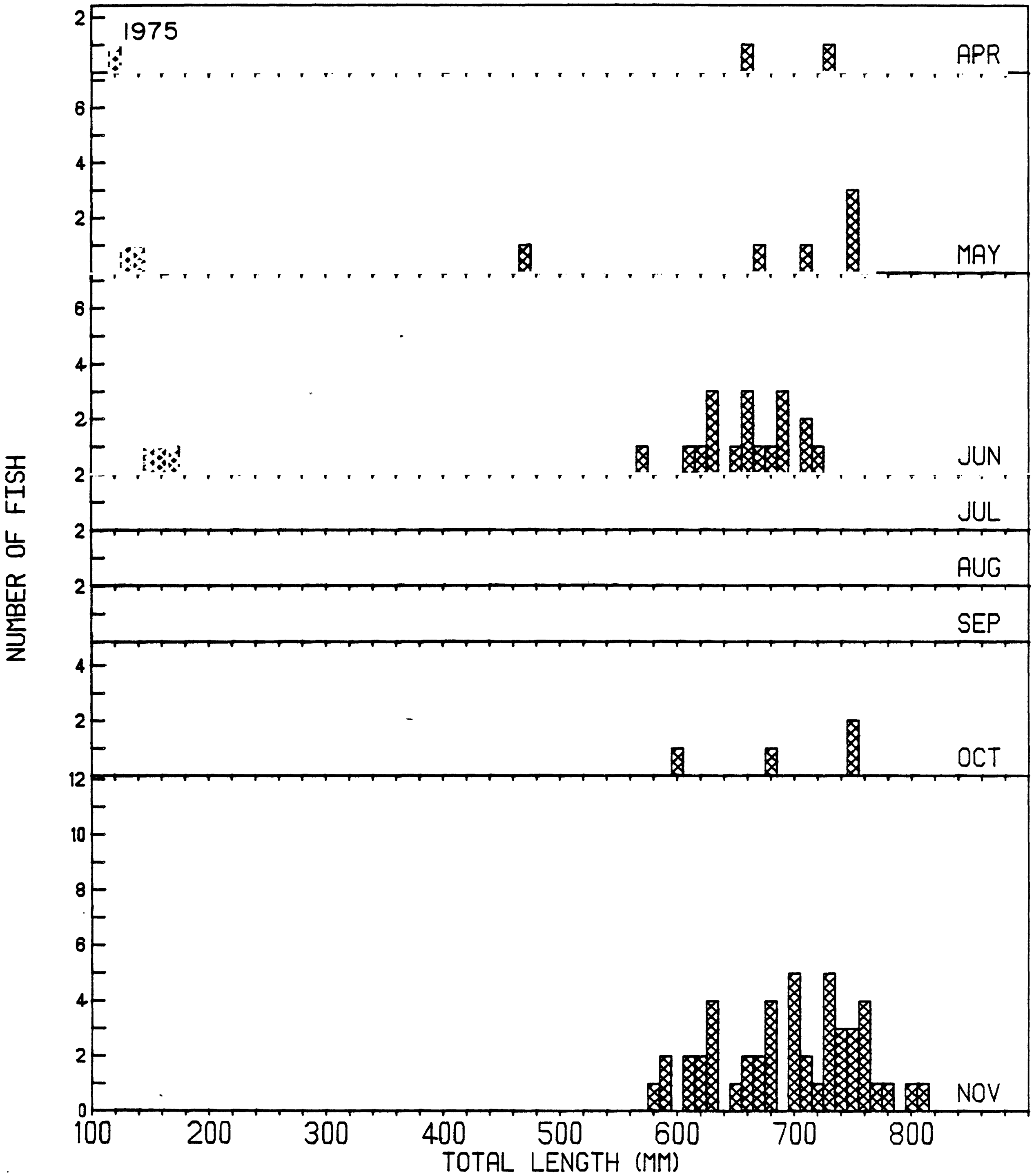

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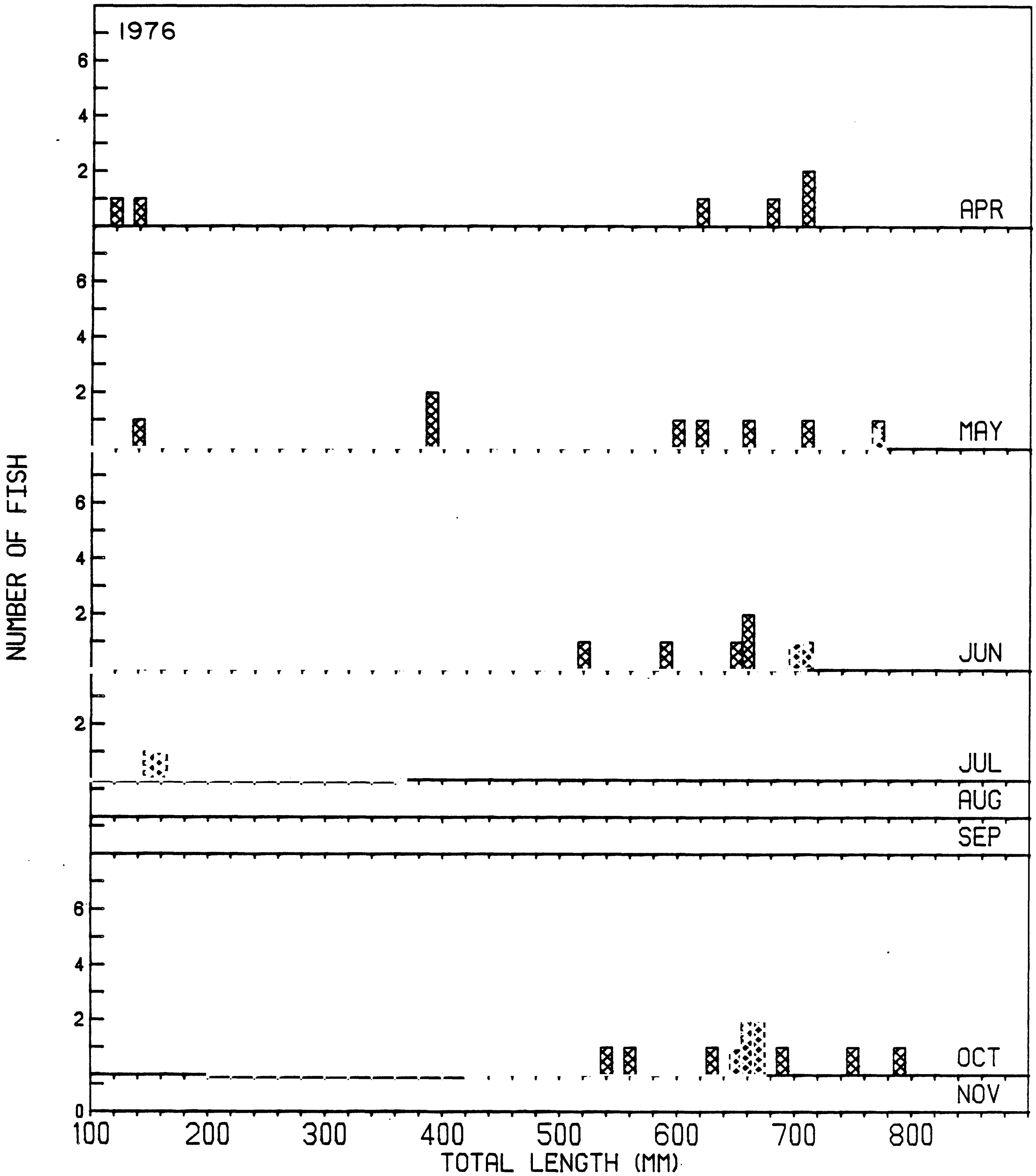

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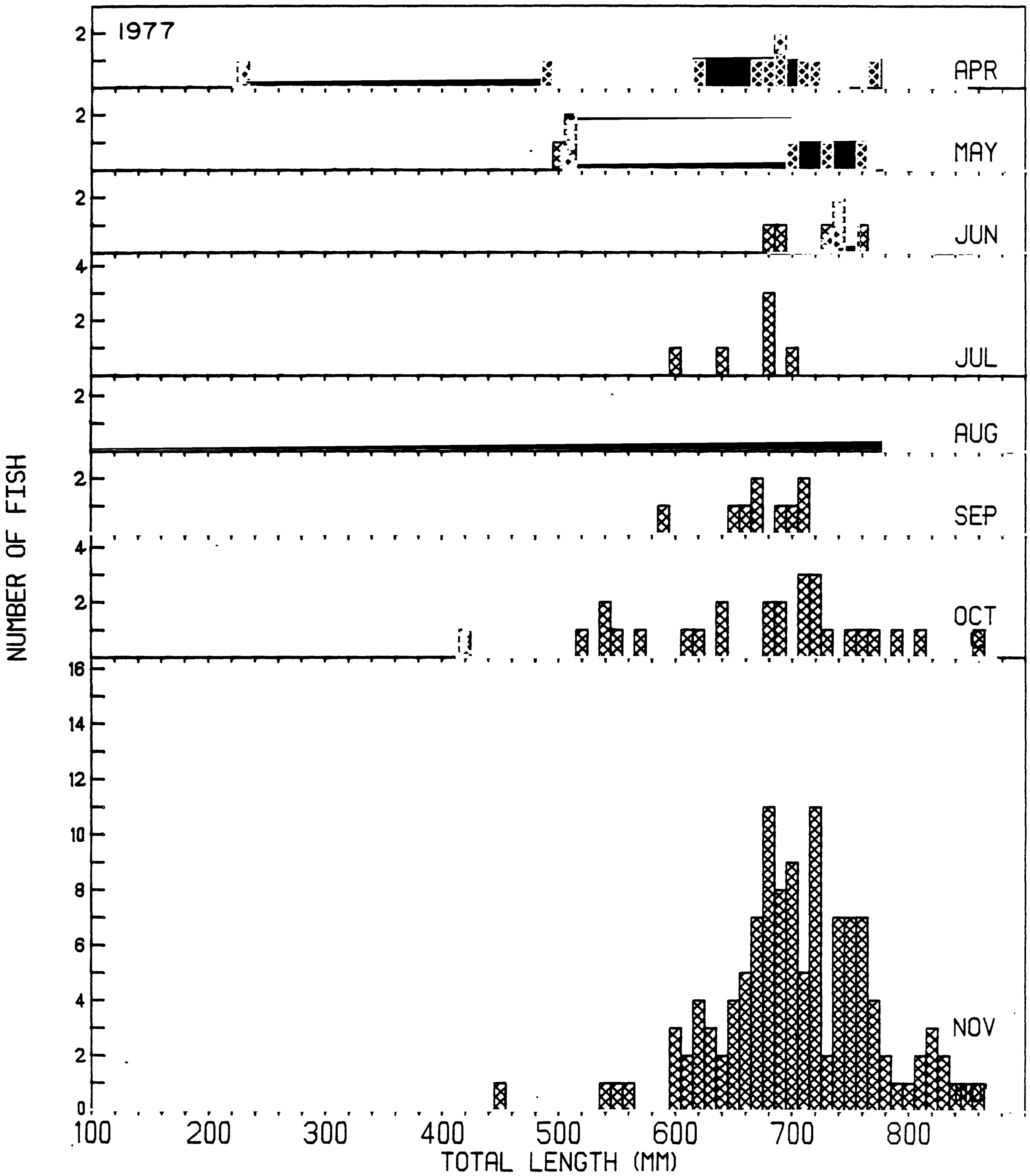

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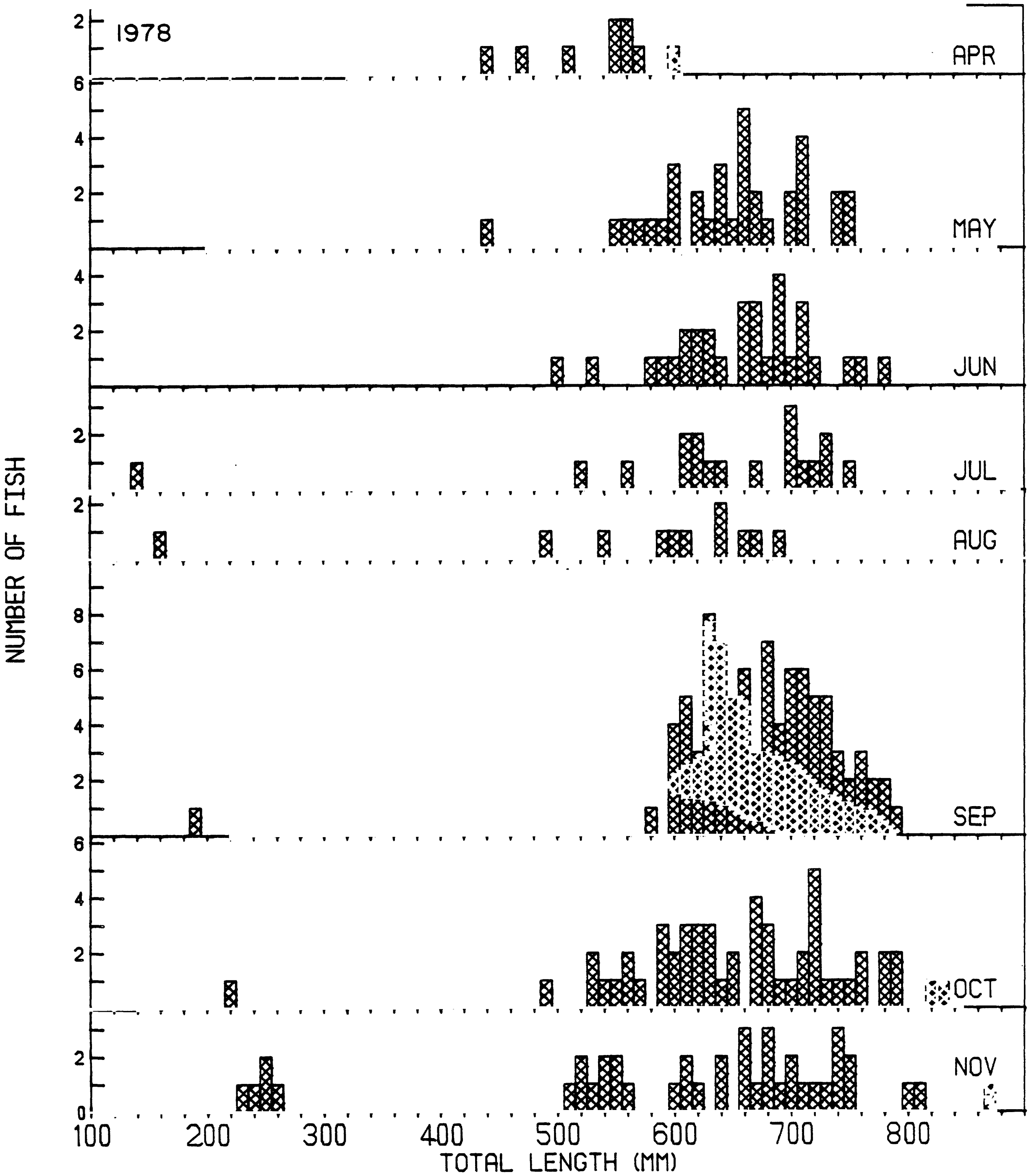

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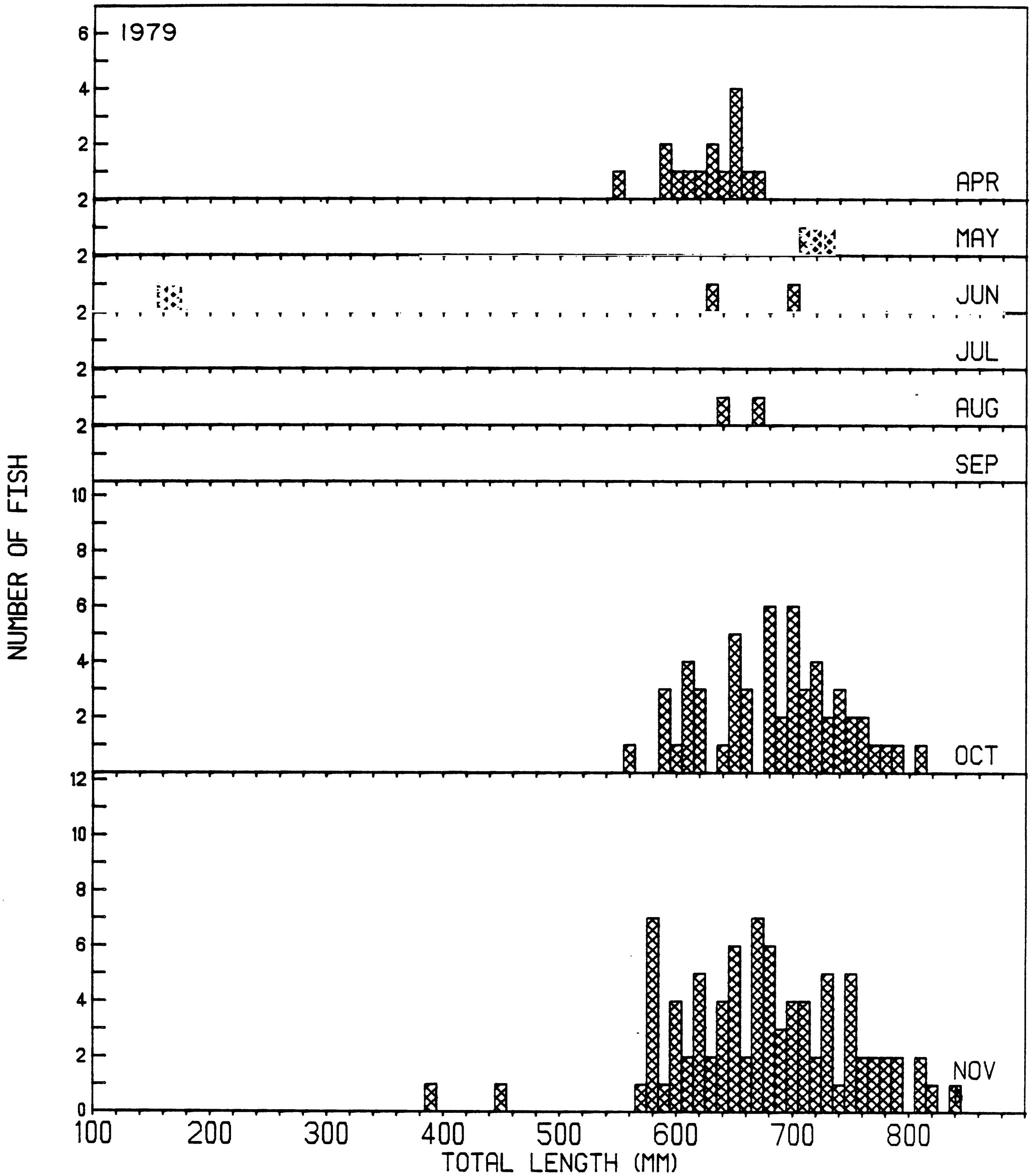

Fig. 99. Continued.

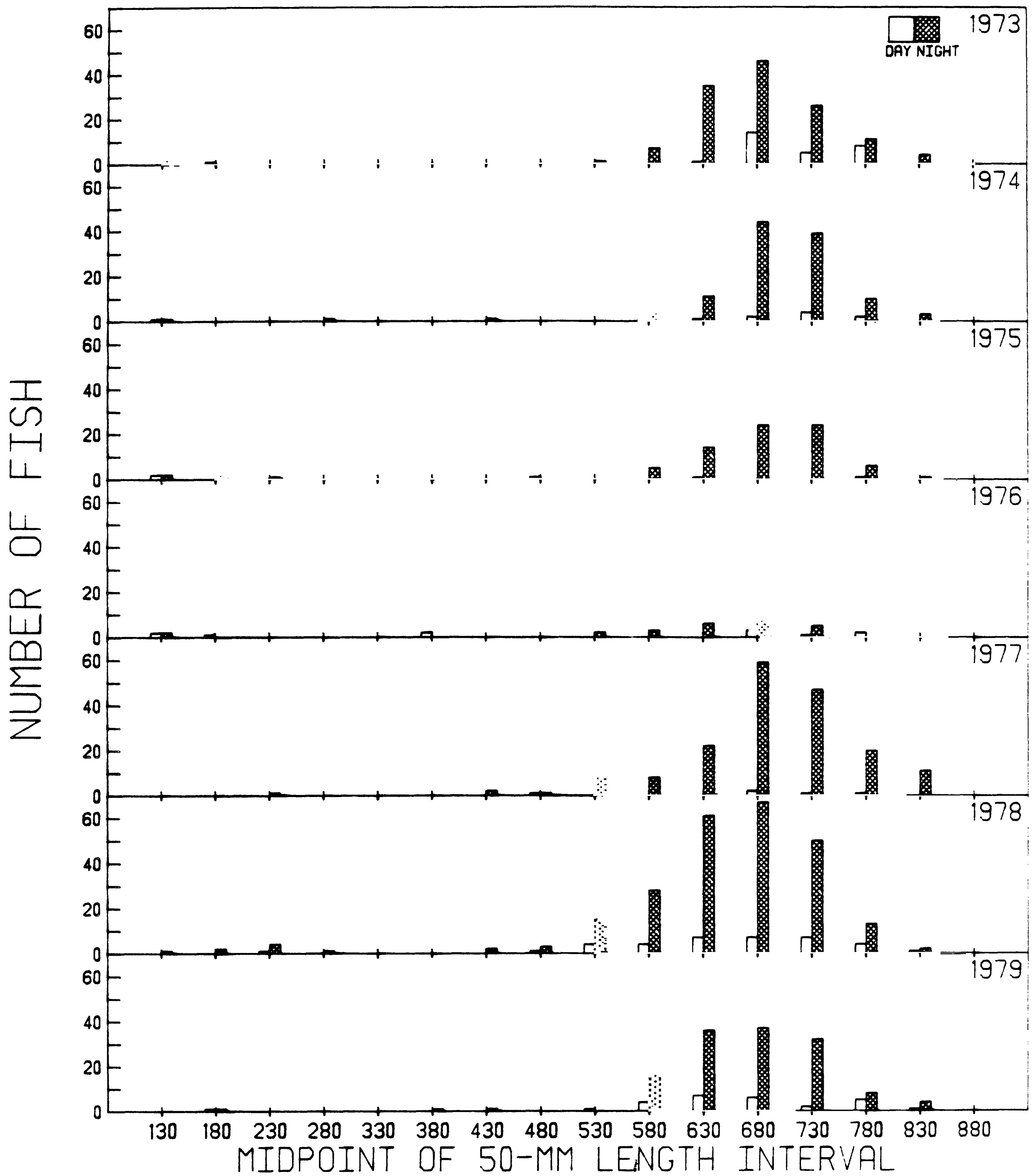

Fig. 100. Length-frequency histograms of lake trout caught by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

Eighty-eight percent of the standard series lake trout catch was taken at night; the difference between day and night catches was significant (Table 63). Lake trout spawn at night (Scott and Crossman 1973), and increased nocturnal activity may account for higher night catches. In addition, during 1974 gill nets set perpendicular to shore from 1.5 to 4 m showed that lake trout move alongshore at night (Jude et al. 1979).

Most lake trout were collected at water temperatures of 6 to 16°C (Fig. 101). Peak abundance occurred at 9°C, similiar to temperature preferenda of 10-11.8°C reported by McCauley and Tait (1970), Scott and Crossman (1973), and Spigarelli (1975). The small peak at 23-25°C (Fig. 101) is due to the large catch in September 1978; this catch comprised 8% of the total 7-year standard series catch. Water temperatures at that time were recorded as 23-25°C (start of set) but the lake trout collected undoubtedly inhabited the 9-10°C water (recorded at end of set) which upwelled during the night. At the Campbell Plant, more lake trout were collected during the summer than at Cook because of lower temperatures during upwellings (Jude et al. 1982). Most adults were captured at water temperatures near 11°C at Cook (Fig. 102), but so few young fish were collected that Figure 102 is not meaningful for fish <400 mm.

Lake trout with sea lamprey scars decreased in frequency from 1973 to 1978, then increased again in 1979 (Table 66). Most scars were healed, and few fish had multiple scars (Table 66). Over the 7 years, 14.4% of the lake trout had lamprey scars or fresh wounds, a lower rate than those found by McComish and Miller (1975) or Jude et al. (1982), 25% and 17-36% respectively. The rates of fish with fresh wounds were similar to those found by Wells (1976, 1980) and Jude et al. (1982), which were 0 to 3.7%. Approximately

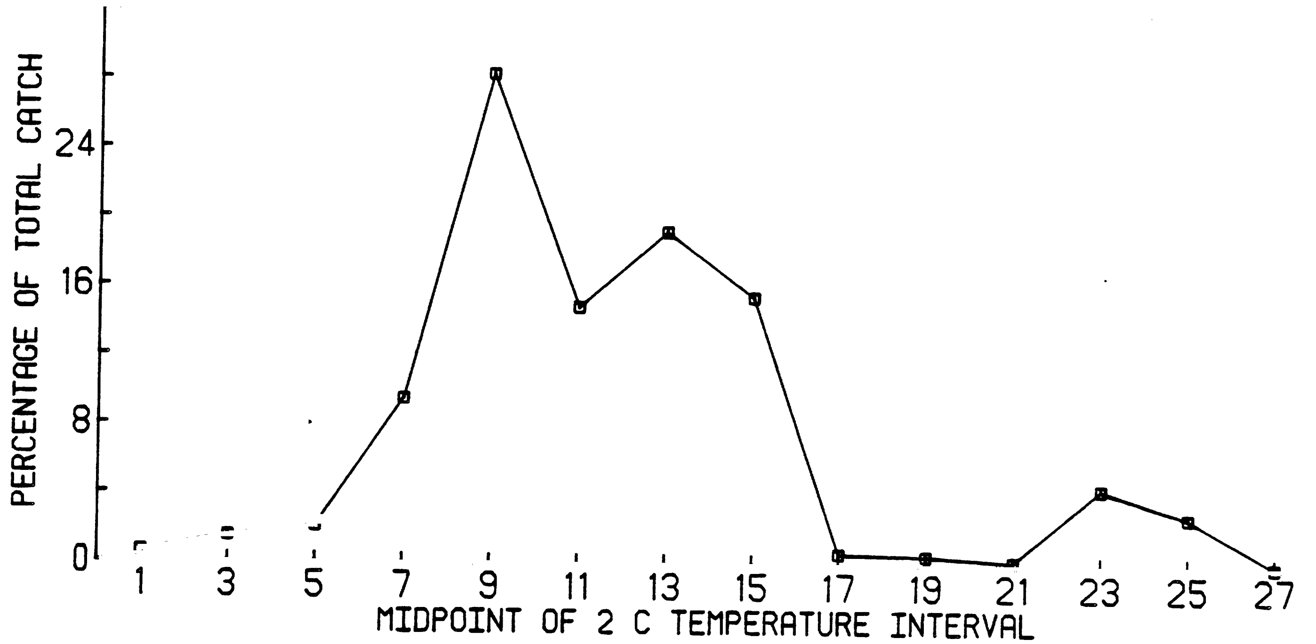

Fig. 101. Percentage of the combined total standard series catch of lake trout collected during 1973-1979 from various temperatures in Cook Plant study areas, southeastern Lake Michigan.

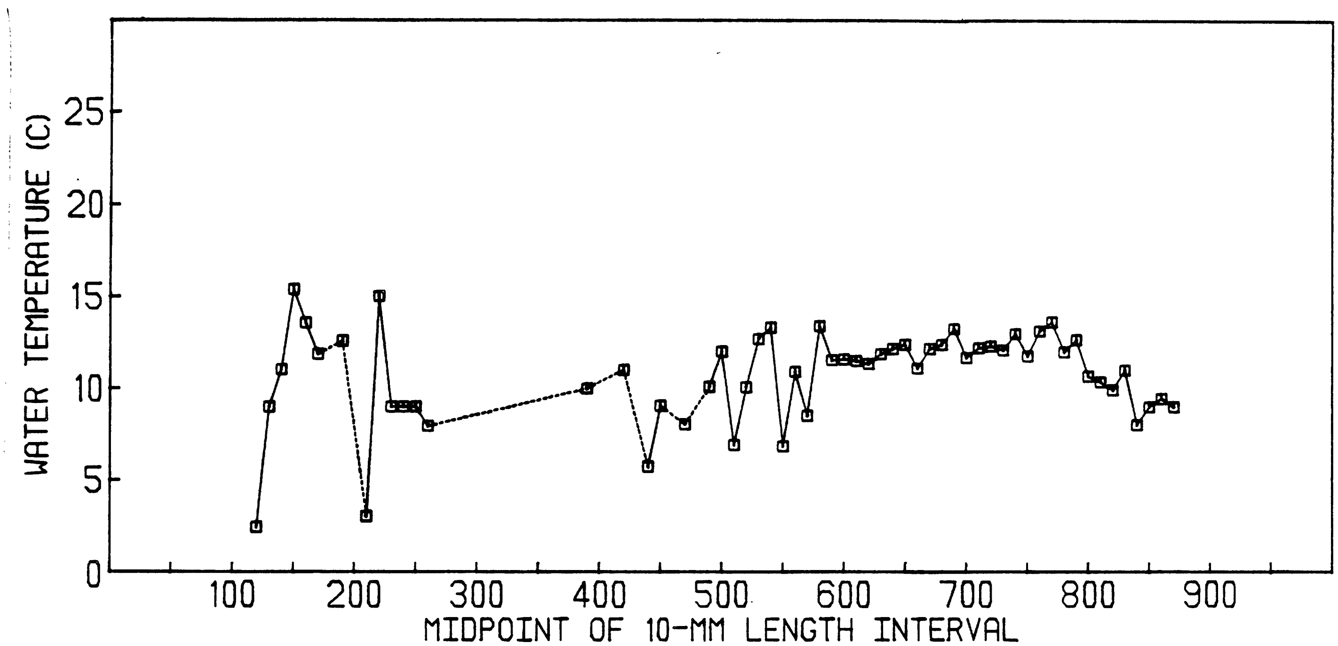

Fig. 102. Mean temperature at which various sizes of lake trout were caught during 1973-1979 by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan.

Table 66. Rates of sea lamprey scarring and occurrence of fresh wounds for all lake trout collected in Cook Plant study areas, southeastern Lake Michigan, 1973-1979. Includes supplementary and impingement samples. ND = no data.

Year	Number of lake trout examined	Percent with lamprey scars or wounds	Percent with > 1 scar	Percent with fresh wounds
1973	218	17.4	ND	ND
1974	209	17.7	ND	ND
1975	236	14.4	ND	ND
1976	109	15.7	7.3	1.8
1977	336	12.7	3.3	2.1
1978	498	10.3	1.2	1.4
1979	325	17.6	3.1	4.0

equal numbers of lamprey scars appeared on the right and left sides of lake trout in our study. Scars appeared on the anterior ventral quadrants of lake trout more often than any other quadrant. Acanthocephalans were rarely noted in the intestines of both adult and immature fish.

About 80% of the lake trout with identifiable food in their stomachs had consumed alewives, and about 15% contained rainbow smelt (from all samples including impingement). Spottail shiner, unidentified sculpin, trout-perch, johnny darter, gizzard shad, yellow perch, bloater, and ninespine stickleback were less common (<1% to 3%) in lake trout stomachs. Most alewives consumed by lake trout were 125-200 mm in length, and most smelt were 100-200 mm. Invertebrates and fish eggs were preyed upon primarily by immature lake trout up to 250 mm. In Indiana waters of Lake Michigan, alewife also is the dominant prey species, and invertebrates are found mainly in small lake trout (McComish and Miller 1975).

Longnose Dace

Operational Effects--

Longnose dace were collected in low numbers every year during 1973-1979. Most longnose dace were caught in seines. Only one specimen was trawled, and none were gillnetted. During both preoperational and operational periods, catches of longnose dace were higher at south Cook (station B) than at north Cook (station A) and Warren Dunes (station F) (Table 67). Longnose dace generally inhabit water with rubble and gravel substrate (Gee and Machniak 1972). Larger catches at south Cook than other beach stations may be related to the presence of rocks and construction debris at station B.

Catches of longnose dace were 41 and 43, respectively, during 1973 and 1974. During 1975-1979, except for the high catch of 60 fish in 1977, annual catches of longnose dace were generally low, ranging from 6 to 27. Lower catches during operational years were observed only at south Cook (station B); catches at north Cook and Warren Dunes were similar between preoperational and operational periods (Table 67). Mean annual catches at south Cook were 31 during 1973-1974 and 15 during 1975-1979. The decline of longnose dace catches may be due to changes of bottom substrate at station B. Sand may be covering over the construction debris left in 1973.

Longnose dace were caught from April to November (Fig. 67). Low catches of longnose dace during spring and early summer may be related to spawning which occurs on rocky substrates (Gee and Machniak 1972) in early summer (Brazo et al. 1978). During July and August, longnose dace probably remained in deeper water. Trautman (1957) reported longnose dace in Lake Erie may migrate offshore to avoid warm inshore water. In our study areas, most

Table 67. Number of longnose dace seined at standard series stations in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

		Cook Plant stations		Warren Dunes station
		North	South	
Year	Time Period	A	B	F
1973	Day	2	3	0
	Night	2	32	2
1974	Day	2	4	3
	Night	8	23	3
1975	Day	0	1	2
	Night	6	8	1
1976	Day	0	4	1
	Night	3	18	1
1977	Day	0	5	5
	Night	25	17	7
1978	Day	0	0	0
	Night	5	19	2
1979	Day	0	0	0
	Night	2	1	3

longnose dace were caught during the fall, except in 1979 when monthly catches were small throughout the year. Largest monthly catches occurred during October 1977. Increase of longnose dace catches during the fall may have been due in part to the presence of YOY which dispersed from nursery grounds during this period. Adults were also more common in the fall than during spring and summer. Occurrence of longnose dace in impingement samples during December, January, and February suggested that this species inhabits the study area during winter also.

Most longnose dace were caught at night (Fig. 103). During the day, longnose dace may be able to avoid the seine or migrate to deeper water.

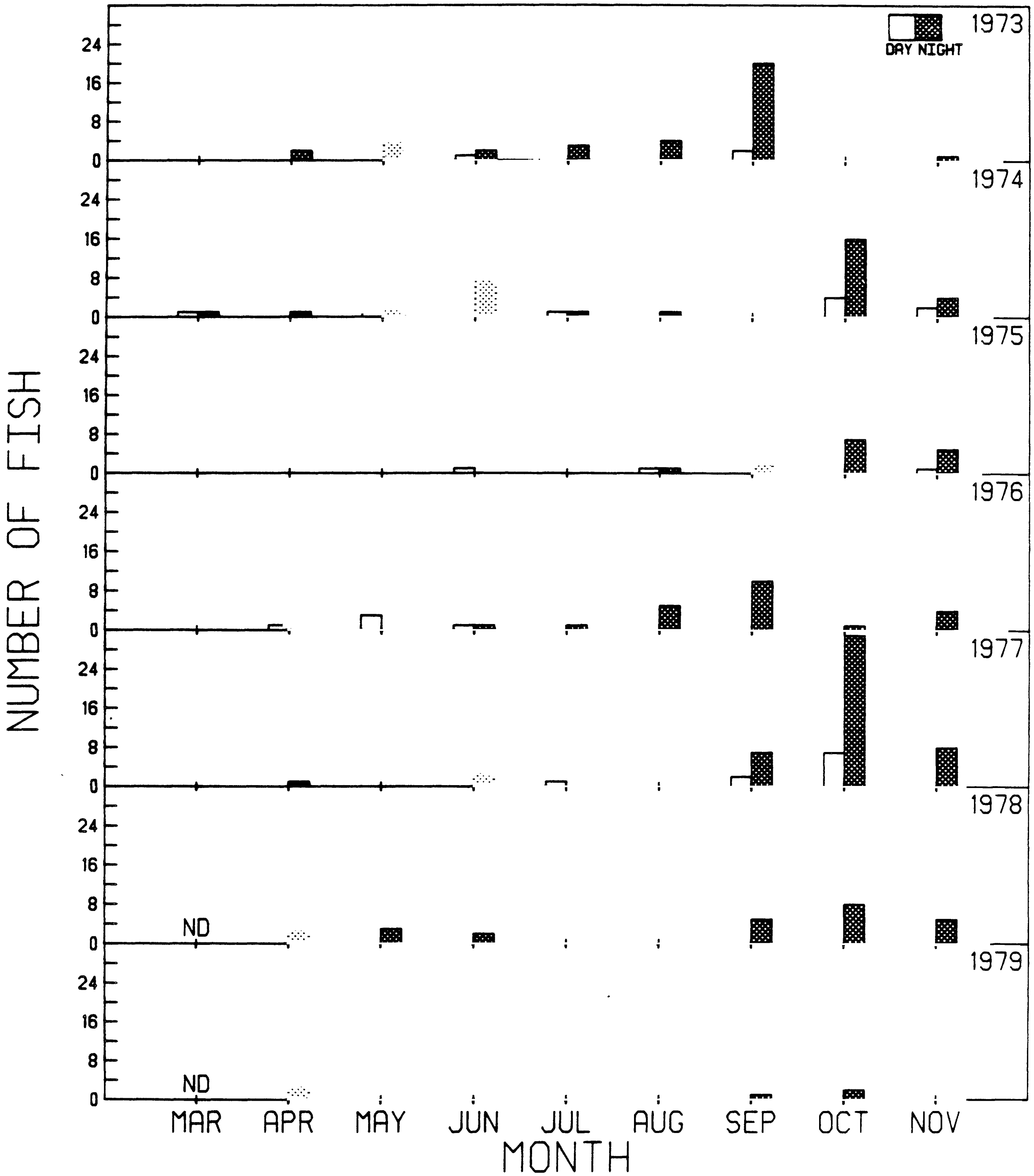

Fig. 103. Number of longnose dace caught by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years. ND = no data.

Brazo et al. (1978) were not able to find longnose dace during the day diving by scuba in the surf zone where numerous fish were caught at night. Occurrence of longnose dace in impingement samples from April to November suggested that this species may commonly move to depths of 7 m where the intake structure is located.

Biological Data--

Longnose dace collected were found in the 20- to 120-mm length intervals; most were 40 to 70 mm (Fig. 104). Based on length-age data for longnose dace from eastern Lake Michigan (Brazo et al. 1978), most fish we collected were YOY and yearlings. Young of the year 20-40 mm were less common than yearlings and adults and were caught most often during September and October. Yearlings approximately 50 to 70 mm occurred from March to November. Adult longnose dace 80 mm and larger were generally caught in the fall.

Longnose dace spawn at age 2 (Bartnik 1970). Spawning occurs on rocky substrates in shallow water (Gee and Machniak 1972). In eastern Lake Michigan, longnose dace spawn from May to late July (Brazo et al. 1978). Lack of ripe adults and larvae suggests that spawning took place outside the study areas.

Longnose dace were caught in water at temperatures from 2 to 27°C, with over 50% being collected at 11 to 15°C (Fig. 105). These data agreed with those of Brazo et al. (1978) who found a substantial increase in longnose dace catches when water temperatures reached 8 to 14°C in spring. In our study areas, young longnose dace tended to occur in wider temperature ranges than larger fish. Longnose dace 20 to 60 mm were found in water temperatures from 5 to 20°C; whereas, fish 70 to 120 mm were found between 11 and 15°C (Fig. 106).

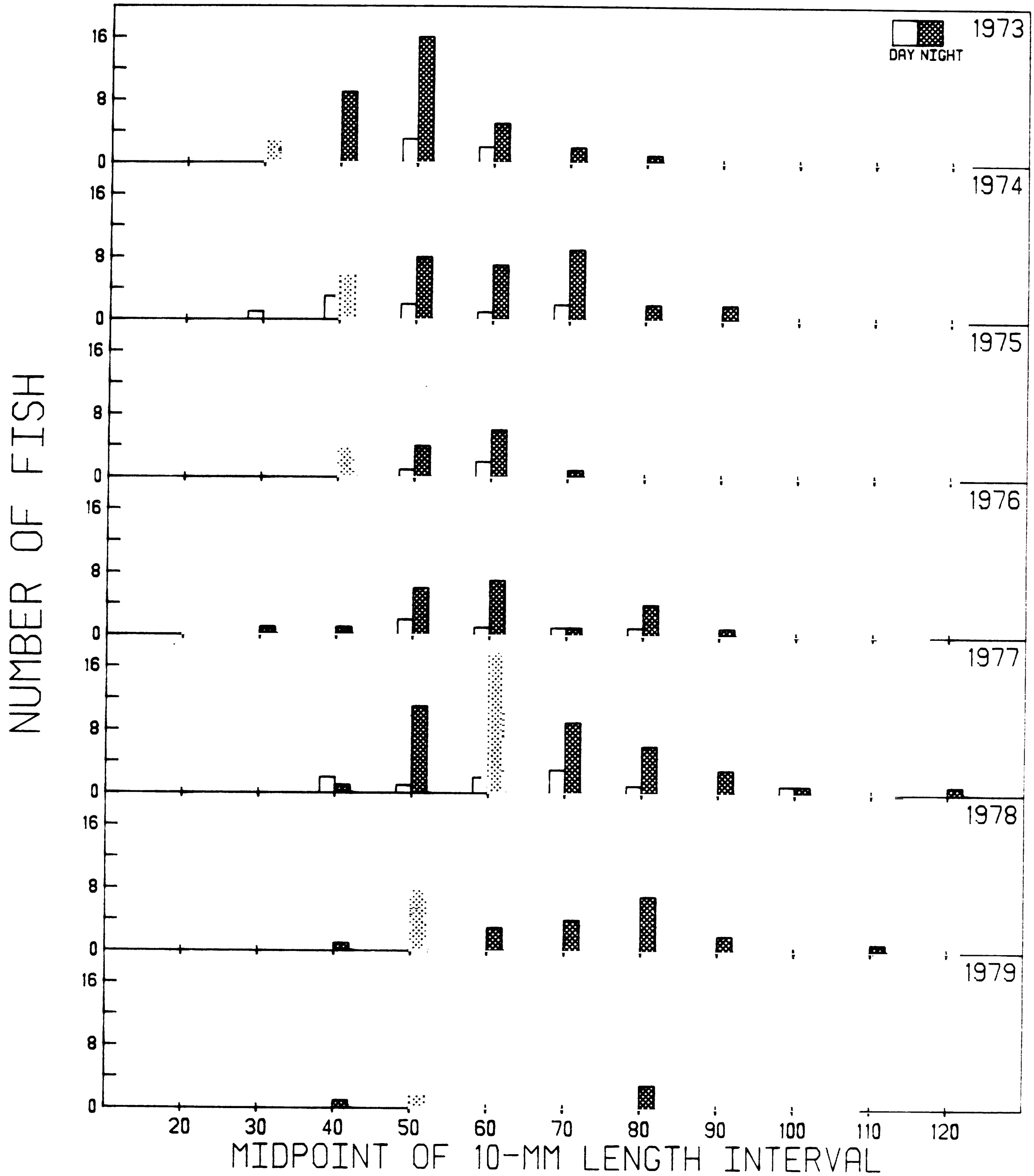

Fig. 104. Length-frequency histograms of longnose dace caught by standard series seining and trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

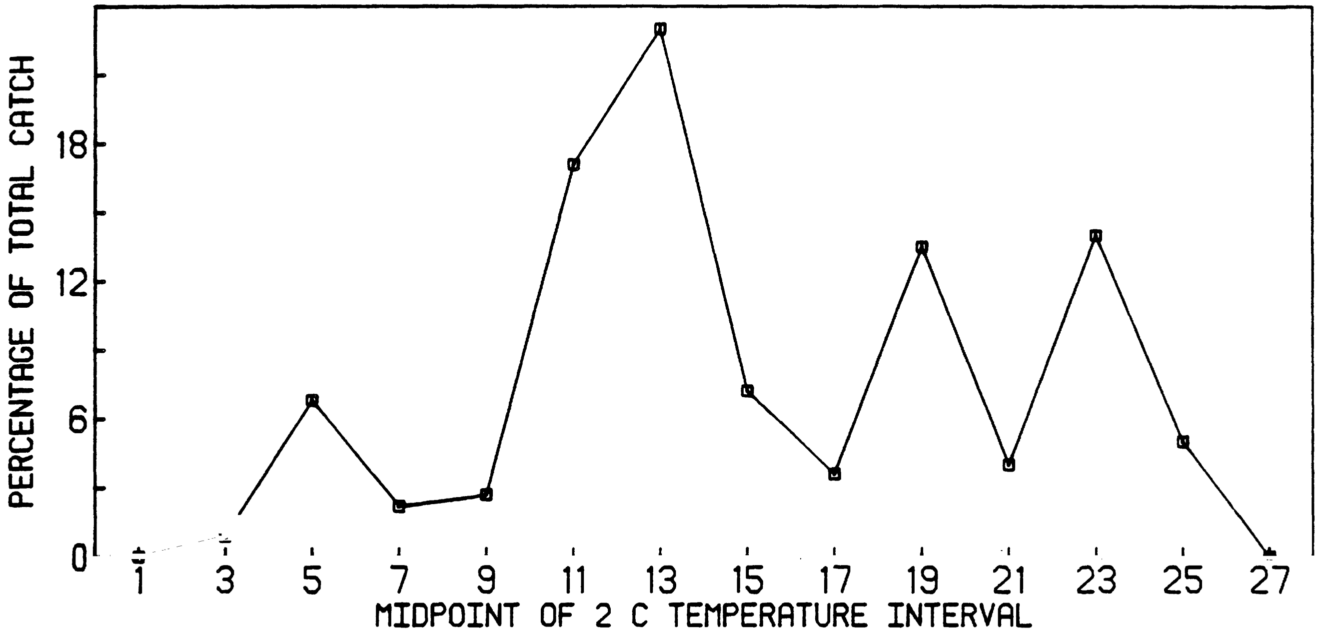

Fig. 105. Percentage of the combined total standard series catch of longnose dace collected during 1973-1979 from various temperatures in Cook Plant study areas, southeastern Lake Michigan.

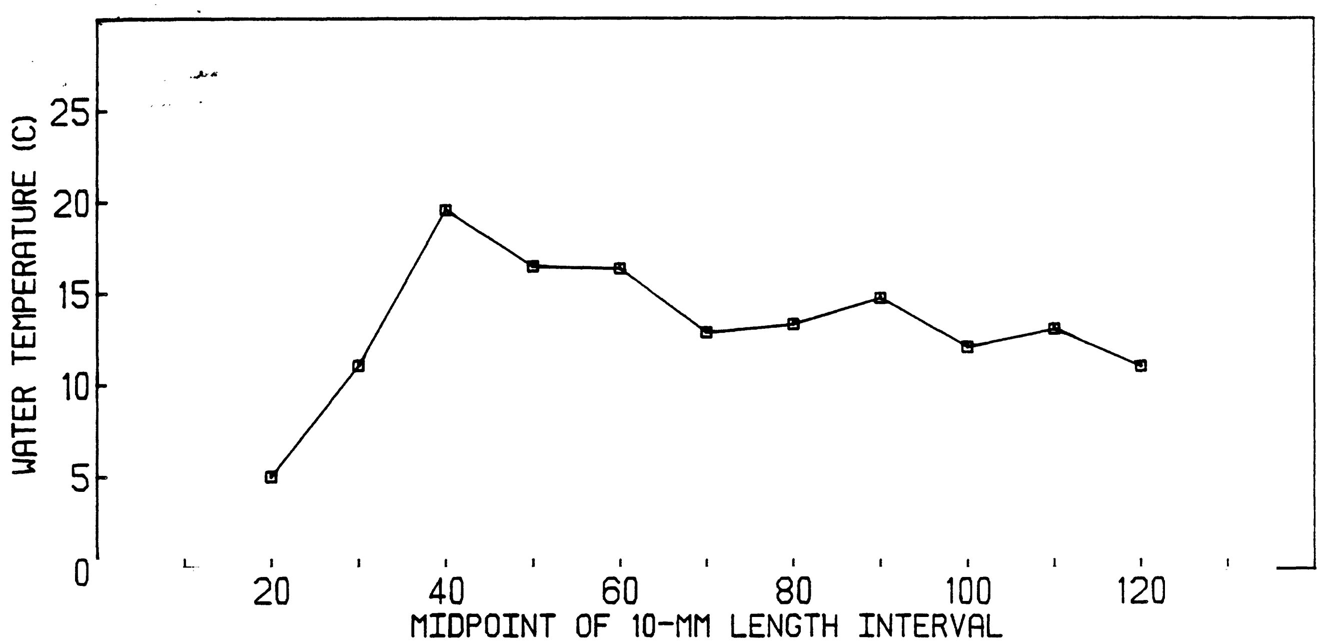

Fig. 106. Mean temperature at which various sizes of longnose dace were caught during 1973-1979 by standard series seining and trawling in Cook Plant study areas, southeastern Lake Michigan.

Longnose Sucker

Operational Effects--

Yearly catches of longnose suckers averaged 82 fish and ranged from 40 fish in 1976 to 99 fish in 1974 and 1977. Gill nets were the most effective gear, with catches averaging 70 fish per year, while trawls and seines averaged, respectively, 10 and 2 fish per year.

As a result of small and sporadic catches, longnose sucker data could not be statistically analyzed; however, data were examined for variations attributable to plant operation. Total catches in preoperational years were in general similar to catches during operational years. Except for the low catch in 1976, yearly catches indicated a stable population in the study area. A comparison of yearly gill net catches showed that longnose suckers were usually more abundant at the Warren Dunes area (Table 68). However, this difference occurred in preoperational years as well as in most operational years. White suckers were also more abundant at Warren Dunes. These two sucker species apparently avoid the plant site presumably because of construction activities and the discharge currents, a finding noted at other power plants on Lake Michigan (Limnetics 1975, Brazo and Liston 1979, Jude et al. 1981).

An examination of yearly gill net catches at stations R and Q (6- and 9-m-deep north Cook stations) also showed no variation attributable to plant operation (Table 68). Catches were similar to those at the south Cook stations and smaller than at Warren Dunes stations.

Biological Data--

Monthly catches of longnose suckers showed no distinct patterns in seasonal abundance (Fig. 107). Longnose suckers were year-round residents, being caught

Table 68. Number of longnose suckers gillnetted at standard series stations and stations R and Q in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years. ND = no data.

		6-m stations			9-m stations		
		Cook Plant		Warren Dunes	Cook Plant		Warren Dunes
		North	South		North	South	
Year	Time Period	R	C	G	Q	D	H
1973	Day	ND	0	0	ND	4	13
	Night	ND	12	19	ND	4	13
1974	Day	ND	2	27	ND	5	14
	Night	ND	12	18	ND	7	9
1975	Day	8	3	0	6	4	1
	Night	2	29	24	7	17	10
1976	Day	0	2	1	2	1	2
	Night	12	10	2	15	11	8
1977	Day	2	0	0	1	0	1
	Night	8	3	44	6	13	19
1978	Day	1	1	0	0	2	4
	Night	6	8	18	8	8	19
1979	Day	2	9	7	2	4	6
	Night	13	6	13	9	8	15

in most months of each year. During most years, there seemed to be a slight abundance peak in late spring and early summer, with low abundance in late summer and early fall. This species may be avoiding inshore waters during the warmest months. Longnose suckers spawned in April (Table 69), presumably in streams and rivers rather than in the study area. Four sucker mesolarvae (species undetermined) were collected in the study area during May 1978, but we presume that they were river-spawned fish which moved into the lake.

Larger catches at night (Fig. 107) resulted from longnose suckers nocturnally moving inshore, although daytime net avoidance may have added to

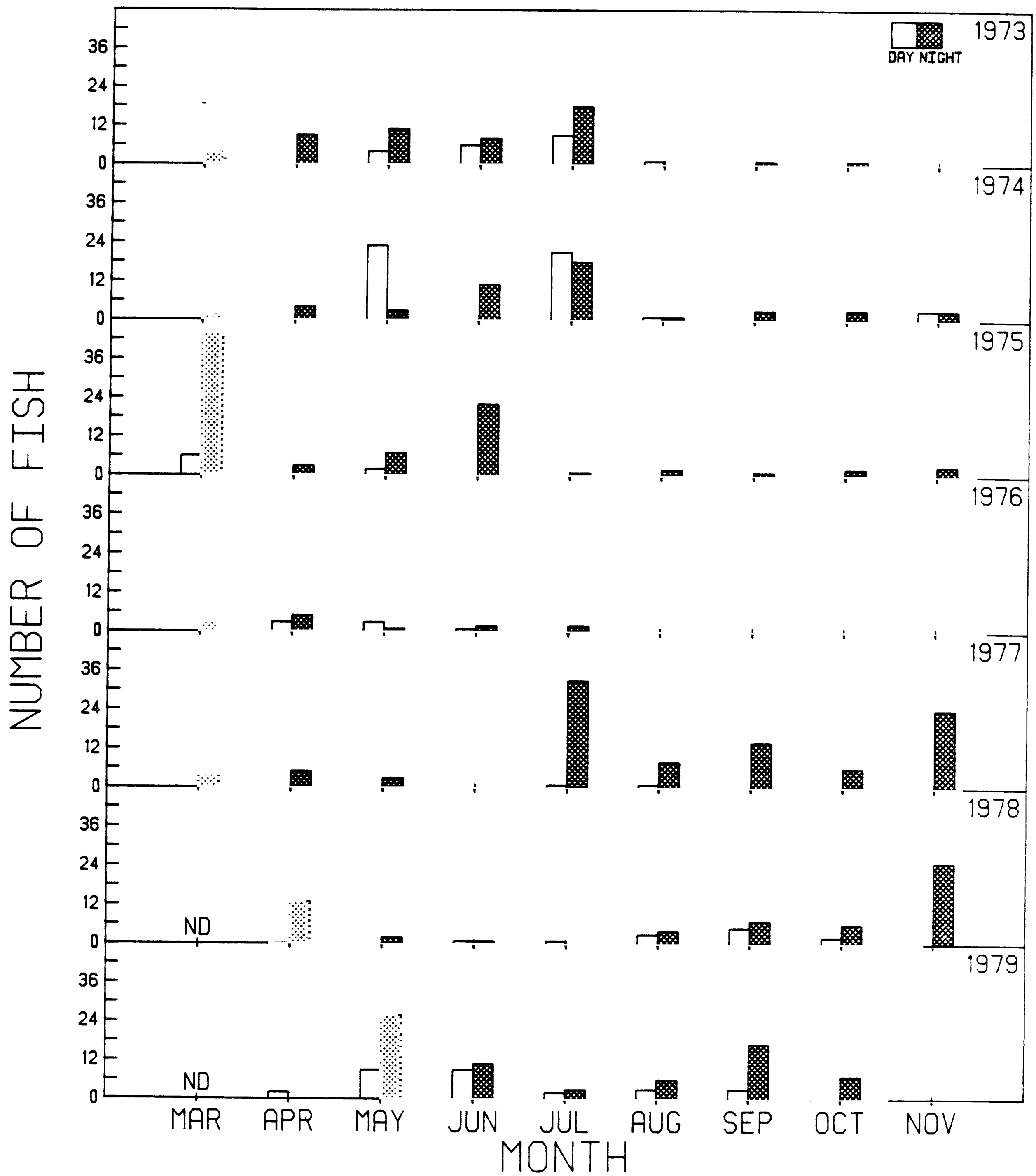

Fig. 107. Number of longnose suckers caught by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years. ND = no data.

Table 69. Number of ripe and spent longnose suckers caught by standard series trawling, gillnetting, and seining in Cook Plant study areas, southeastern Lake Michigan, 1973-1979. F = female, M = male, ND = no data.

Year	Sex	Gonad condition	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	F	Ripe	2	0	0	0	0	0	0	0	0	0
		Spent	2	0	1	9	20	0	0	0	0	0
	M	Ripe	0	2	0	0	0	0	1	1	0	0
		Spent	0	0	5	5	3	0	0	0	0	0
1974	F	Ripe	0	1	0	0	0	0	0	0	3	1
		Spent	0	2	10	0	14	0	0	0	0	0
	M	Ripe	0	0	0	3	0	0	0	0	2	0
		Spent	0	0	12	0	5	0	0	0	0	0
1975	F	Ripe	31	1	3	7	0	0	0	0	1	0
		Spent	0	2	0	11	0	0	0	0	0	0
	M	Ripe	10	0	0	3	0	0	0	0	2	0
		Spent	0	0	1	0	0	0	0	0	0	0
1976	F	Ripe	2	3	0	0	0	0	0	0	0	ND
		Spent	1	4	2	0	0	0	0	0	0	ND
	M	Ripe	0	0	0	0	0	0	0	0	0	ND
		Spent	0	1	1	0	0	0	0	0	0	ND
1977	F	Ripe	2	0	0	0	10	0	1	3	8	0
		Spent	0	3	1	0	1	0	0	0	0	0
	M	Ripe	2	0	0	0	7	0	1	0	13	0
		Spent	0	2	1	0	0	0	0	0	0	0
1978	F	Ripe	ND	1	0	0	0	0	1	1	12	ND
		Spent	ND	5	1	0	0	0	0	0	0	ND
	M	Ripe	ND	3	0	0	0	0	0	2	10	ND
		Spent	ND	0	0	0	0	0	0	0	0	ND
1979	F	Ripe	ND	0	1	0	0	2	0	1	0	ND
		Spent	ND	0	12	2	0	0	0	0	0	ND
	M	Ripe	ND	0	0	0	0	1	0	3	0	ND
		Spent	ND	0	7	0	0	0	0	0	0	ND

the difference. During daylight, fish were apparently distributed deeper than 9 m. At night fish were equally distributed at 6 and 9 m. Small seine catches showed that longnose suckers rarely moved into water as shallow as 1 m. Emery (1973) observed that longnose suckers move inshore (8-12 m) to feed at night in Georgian Bay, Lake Huron.

Most longnose suckers collected in the study area were adults (Fig. 108). In contrast to the Ludington, Michigan, area where most longnose suckers collected ranged from 230 to 440 mm in length and only four fish were over 500 mm (Brazo and Liston 1979), we collected many fish over 500 mm. This regional difference, like that of the white sucker, may be related to the lack of exploitation in the southern end of the lake and possibly to better growth in our study area. Very few juveniles were collected, and only in 1977 and 1979 were notable numbers of YOY found. Although the data are meager, modal lengths of YOY in August of most years were approximately 90-110 mm. Broad length ranges of YOY indicated considerable variation in growth within and between years.

Although longnose suckers were caught over a wide temperature range, they tended to be caught at lower temperatures (Fig. 109). Few fish were caught at temperatures above 20°C; apparently this species avoids warmer water. This is in contrast to white suckers which were frequently caught at temperatures above 20°C. However, longnose suckers were similar to white suckers in that smaller fish were caught at higher temperatures than larger fish (Fig. 110), because younger fish preferred warmer water than older fish or nursery areas were located in shallow water which is warmer than deeper water where most adults were collected.

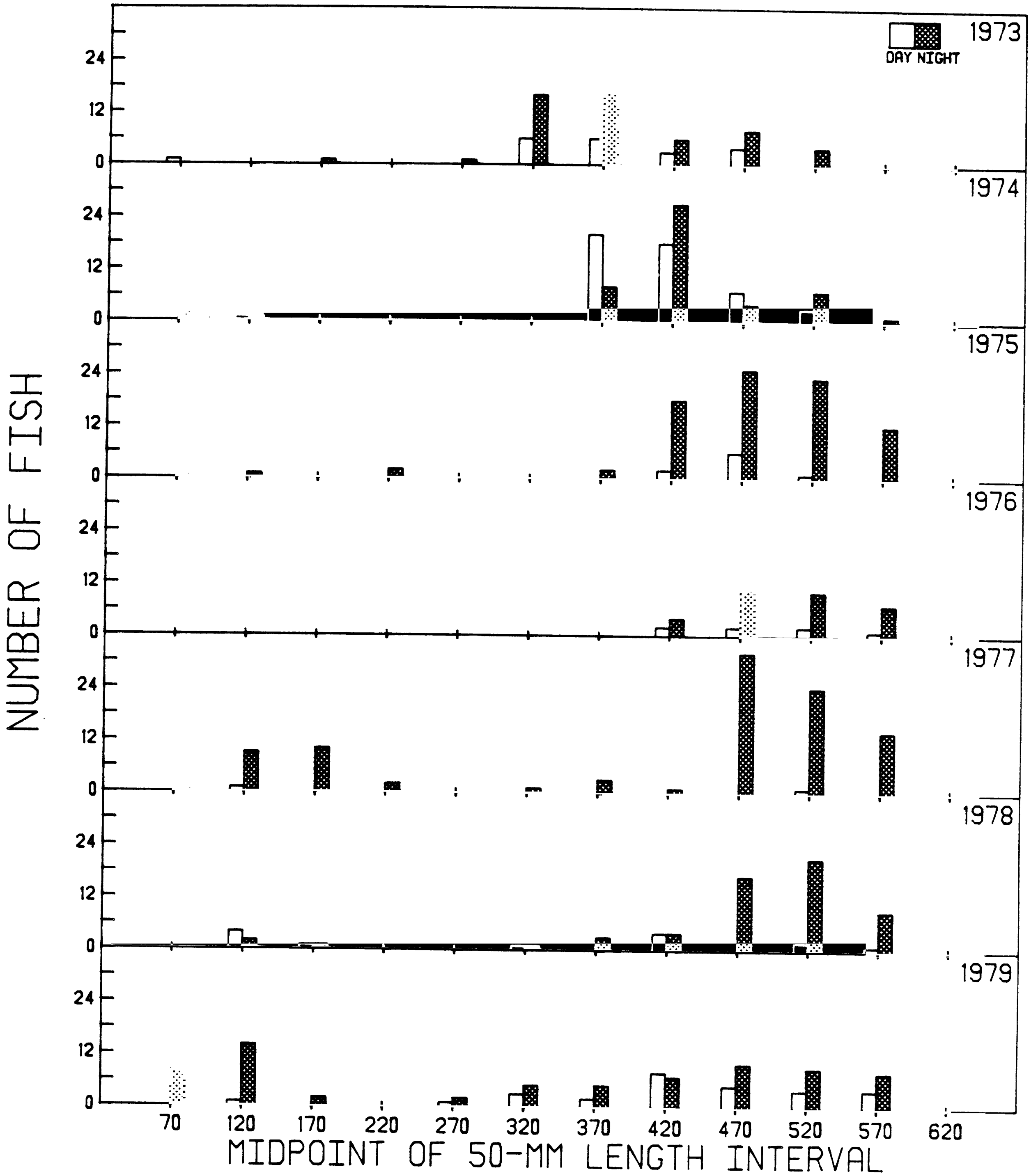

Fig. 108. Length-frequency histograms of longnose suckers caught by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

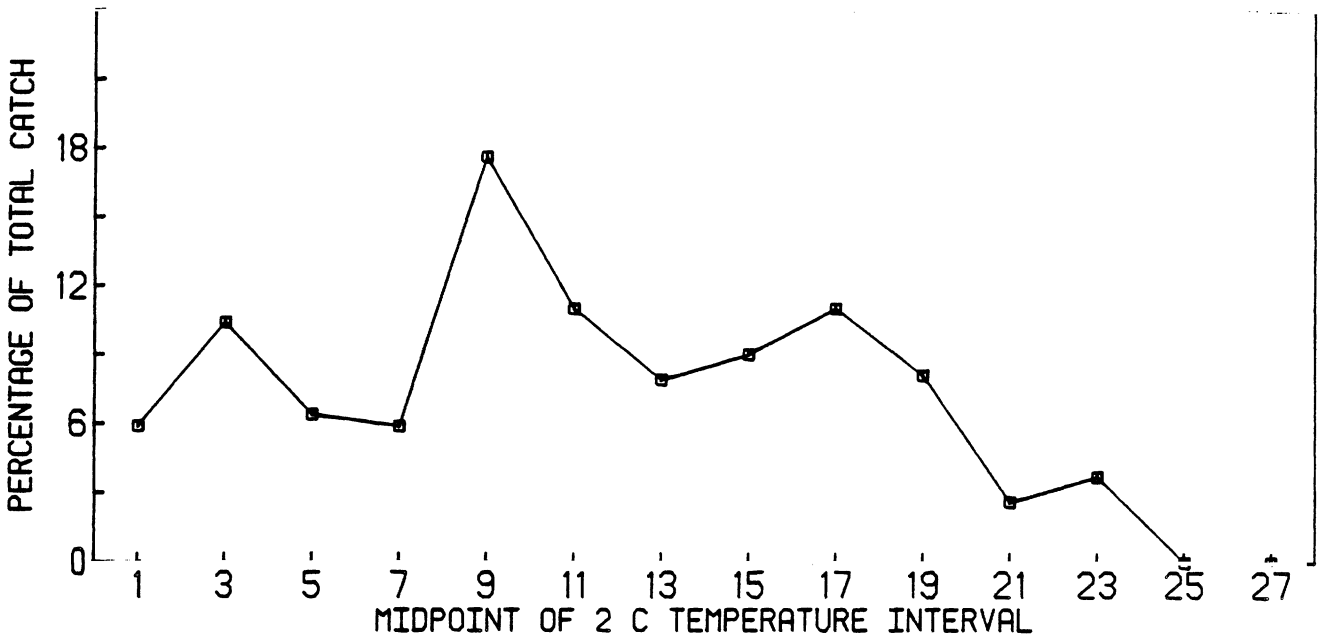

Fig. 109. Percentage of the combined total standard series catch of longnose suckers collected during 1973-1979 from various temperatures in Cook Plant study areas, southeastern Lake Michigan.

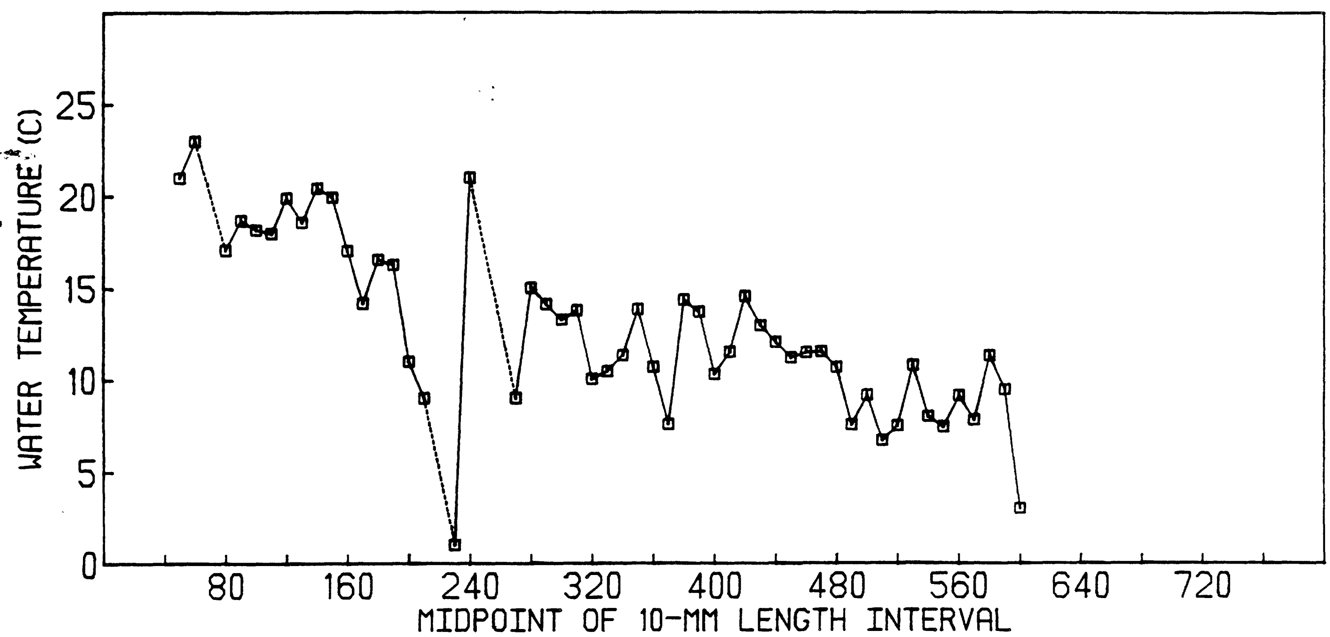

Fig. 110. Mean temperature at which various sizes of longnose suckers were caught during 1973-1979 by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan.

Longnose suckers with neoplastic lesions on the lips and heads, first noted in preoperational years (Jude et al. 1979), were also found in operational years. No yearly changes in number of suckers afflicted with these lesions were evident. Number of fish inflicted varied from no fish in 1978 to four fish in 1975. Identical lesions, under gross examination, were also found on a few white suckers.

Rainbow Trout

Operational Effects--

Rainbow trout were less common than most salmonid species collected in the study area during 1973-1979. Most rainbow trout were caught in seines; a few were found in gill nets and trawls. Annual catches ranged from 8 fish in 1974 to 86 in 1973. Most rainbow trout collected in 1973 were juveniles 100-300 mm, suggesting that the unusually large 1973 catches may be related to a strong year class. Both adults and juveniles appeared to be avoiding the study area in 1974, resulting in relatively small catches during that year. The above data indicated high variability of rainbow trout catches during the preoperational period. Catches were generally stable during operational years (Table 70). During 1975-1979, mean annual catches at Cook stations (4) were similar to those at Warren Dunes (5), suggesting that plant operation had little impact on rainbow trout populations. Rainbow trout were reported to be attracted to the plume area near power plants (Spigarelli and Thommes 1979). The influence of heated water on rainbow trout at the Cook Plant could not be detected in this study, due to low abundance of this species.

Table 70. Number of rainbow trout seined at standard series stations in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

Year	Time Period	Cook Plant stations North A	Cook Plant stations South B	Warren Dunes station F
1973	Day	8	16	11
	Night	14	23	11
1974	Day	1	2	1
	Night	2	1	0
1975	Day	3	1	4
	Night	1	2	1
1976	Day	0	4	1
	Night	3	4	1
1977	Day	1	0	4
	Night	2	2	0
1978	Day	0	3	2
	Night	2	6	5
1979	Day	0	2	4
	Night	1	2	2

Monthly catches of rainbow trout varied considerably during 1973-1979. Rainbow trout was generally common in spring when they migrated inshore (Fig. 111). Catches were relatively high during April and May. In 1974 and 1975, however, no rainbow trout were collected in May. During summer, catches were generally small, presumably due to warming of inshore water. Rainbow trout were, however, caught in summer every year except in 1974. Relatively large catches were made during June, July, and August 1973 and August 1978. Summer catches consisted mainly of juveniles, which generally tolerated warmer water than adults (see Biological Data). In contrast to brown trout and salmon, rainbow trout were relatively more common during fall. Rainbow trout

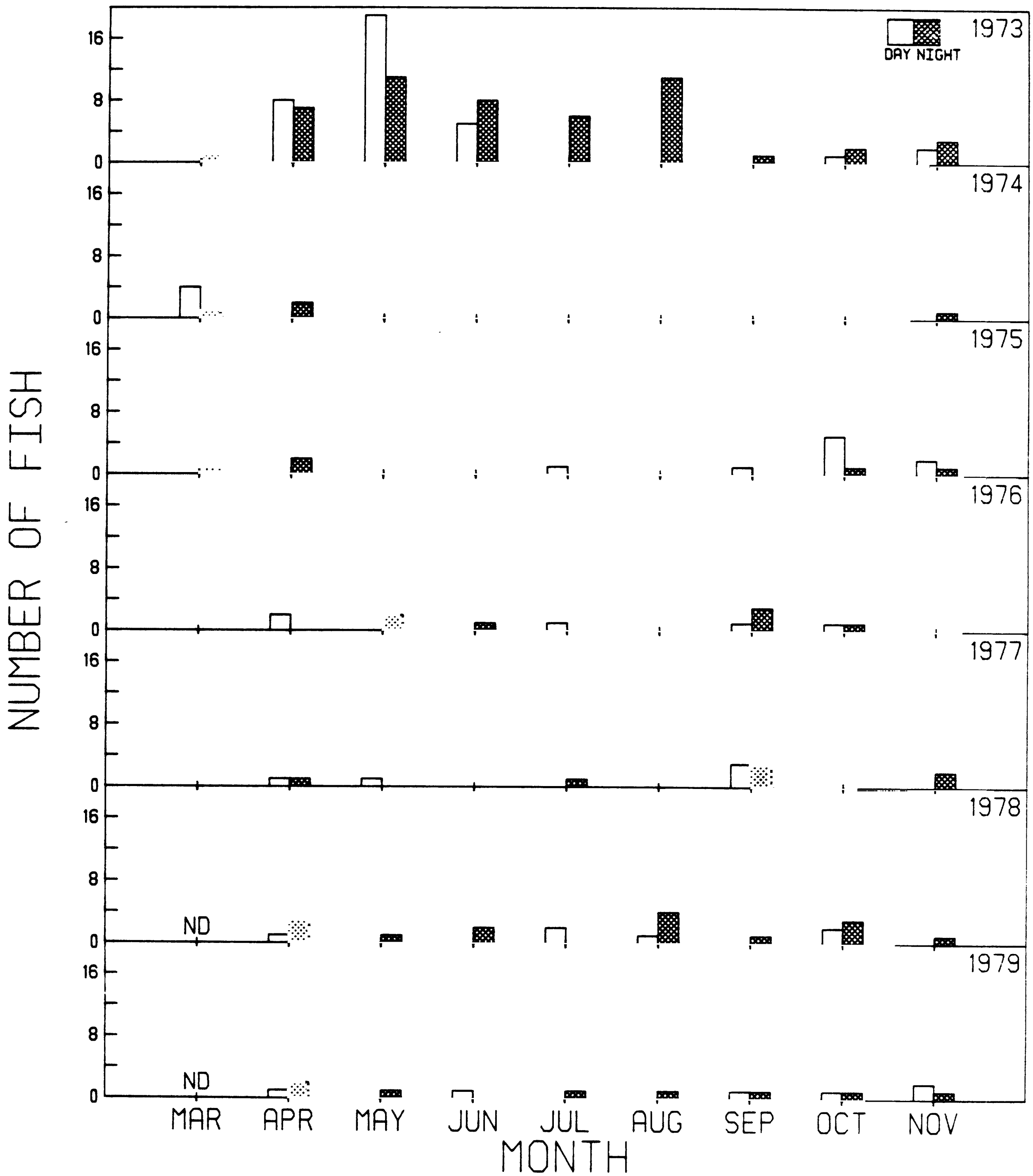

Fig. 111. Number of rainbow trout caught by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years. ND = no data.

returned to shallow areas in fall, but probably did not migrate upstream until late fall or early spring. Reasons for unusually small catches during fall 1974 are not known. Night catches were slightly higher than day catches.

Biological Data--

Rainbow trout collected were in the 50- to 770-mm length interval (Fig. 112). YOY caught in October and November were from 50 to 110 mm. This size range was comparable to the mean length of approximately 82 mm for YOY rainbow trout in the Great Lakes at the end of the first year of life (MacCrimmon and Gots 1972). Stauffer (1972) reported a smaller mean length (74 mm) for age-0 rainbow trout in Lake Superior. Offsprings of lake-resident rainbow trout that were produced in streams may remain in streams from a few months to 4 years before migrating to lakes (MacCrimmon and Gots 1972). Presence of YOY in the study area in October and November suggested that some juvenile rainbow trout migrated from tributary streams to Lake Michigan during the fall of the first year of life.

Rainbow trout in the Black River, Michigan, grew to a mean length of 163 mm during the second year ot life (Stauffer 1972). Yearlings we collected during spring reached a comparable size range (130-280 mm). These data suggest that plant operations did not affect the growth rate of juvenile rainbow trout.

Rainbow trout larger than 300 mm were relatively uncommon in the study area. Most were found in spring and fall. In the Great Lakes region, rainbow trout spawn from late December to late April (Dodge and MacCrimmon 1970). A few ripe males occurred in our study area during September-November. All spent adults were, however, caught during April and May, suggesting that spawning in the vicinity of the Cook Plant took place during early spring.

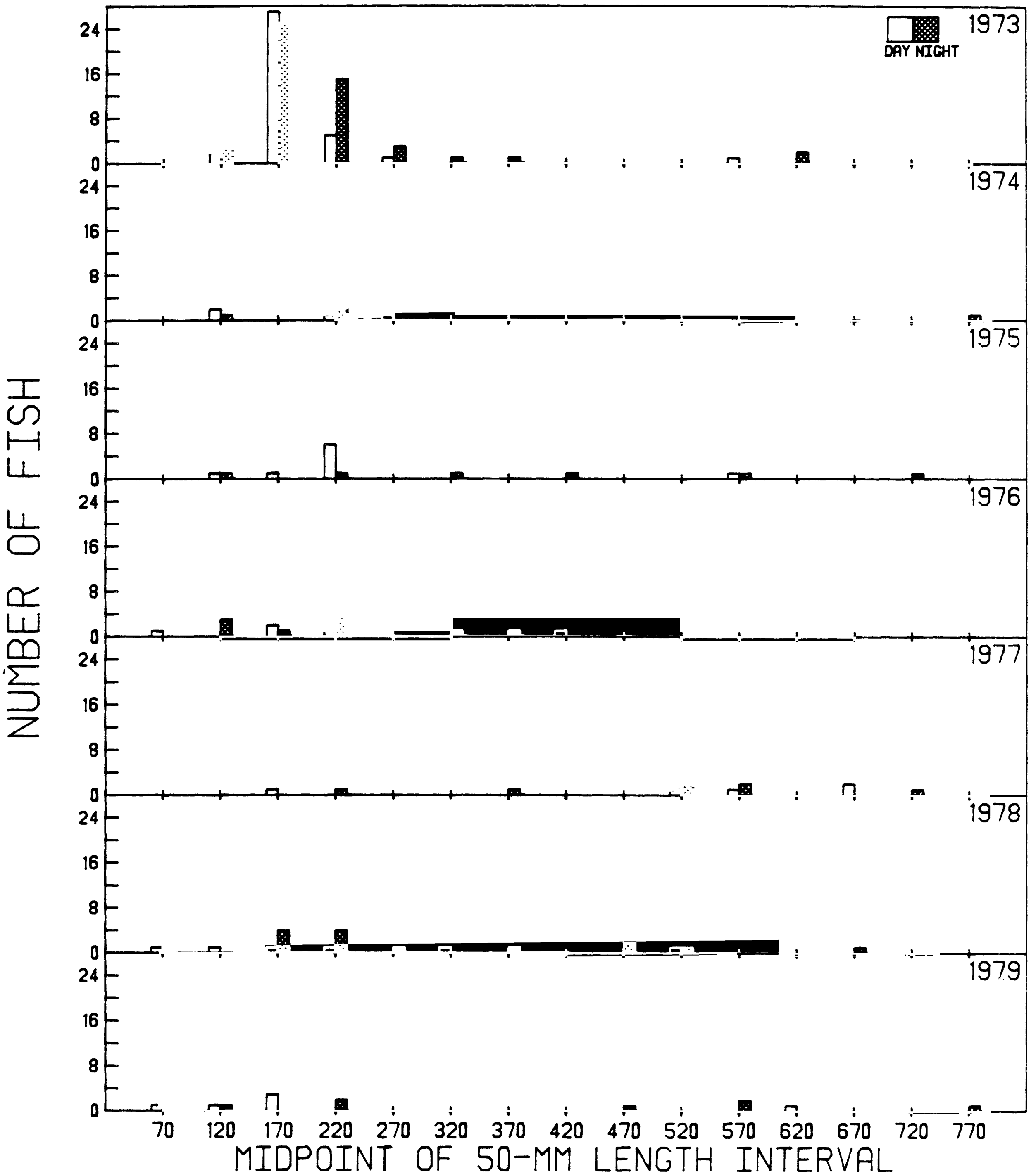

Fig. 112. Length-frequency histograms of rainbow trout caught by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

These data agree with Scott and Crossman (1973), who reported most rainbow trout were spring spawners.

Rainbow trout were caught in a wide range of temperatures (1-27°C), most being found in water temperatures from 5 to 17°C (Fig. 113). Juveniles 60-240 mm occurred most often in water temperatures from 10 to 22°C. These data are in agreement with Javaid and Anderson (1967) who reported that juveniles acclimated at water temperatures of 10, 15, and 20°C preferred temperatures of 15.8, 17.5, and 22°C, respectively. Rainbow trout larger than 240 mm were generally found in cooler water (3-18°C) than younger individuals (Fig. 114). Spigarelli and Thommes (1979) also found an inverse relationship between preferred temperature and size of rainbow trout.

Slimy Sculpin

Operational Effects--

Slimy sculpins were caught by standard series fishing every year of the study but overall comprised only 0.08% of the total catch from 1973 to 1979. Difficulty in distinguishing mottled sculpins from slimy sculpins during 1973 to 1976 sometimes resulted in grouping them as slimy sculpins (Jude et al. 1979). However, mottled sculpins were believed to comprise no more than a very small portion of the total sculpin catch, and any bias resulting from including some mottled sculpins with the slimy sculpin catch is believed negligible. Trawling caught most (87.2%) of the slimy sculpins every year with seining accounting for the remainder. Only two slimy sculpins were gillnetted from 1973 to 1979. Because trawl catches comprised most of the total slimy sculpin catch, these data were examined for possible plant effects.

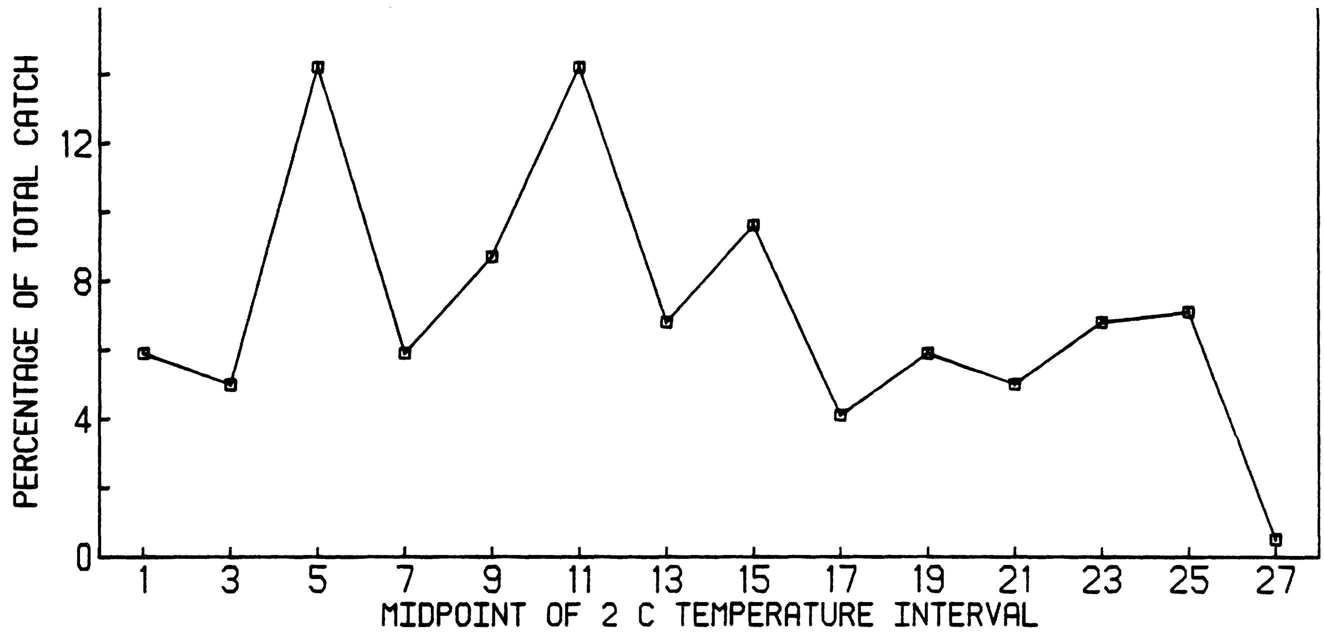

Fig. 113. Percentage of the combined total standard series catch of rainbow trout collected during 1973-1979 from various temperatures in Cook Plant study areas, southeastern Lake Michigan.

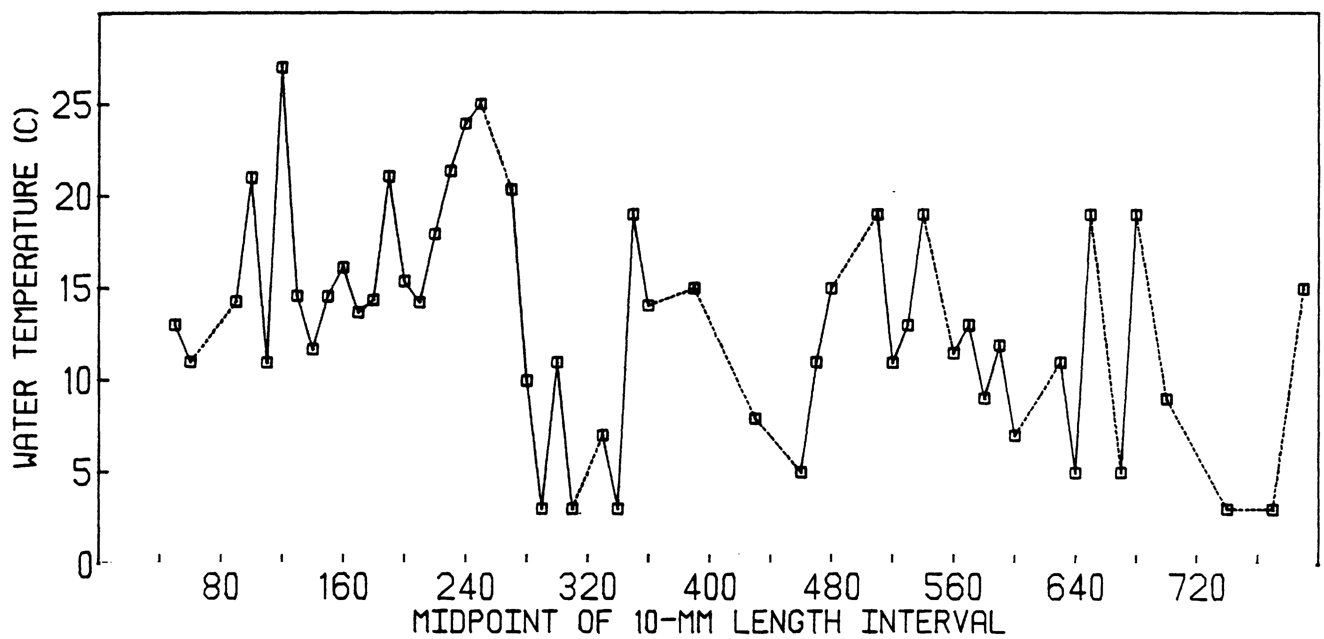

Fig. 114. Mean temperature at which various sizes of rainbow trout were caught during 1973-1979 by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan.

Differences in trawl catches among years were significant (Table 71). Multiple range testing indicated that the 1974 catch was significantly larger than the catches of all other years. The 1977 and 1978 catches were smallest and the remaining years were similar. Jude et al. (1979) documented sculpins colonizing riprap at the Cook Plant intake and discharge structures as a reason for increasing catches during preoperational years. Subsequent catch declines at Cook during operational years may have been an effect of plant operation or a natural population decrease. Frequency of occurrence of slimy sculpins in impingement samples (unpublished data, Great Lakes Research Division) was large relative to field catches. Therefore, during preoperational years the close association of slimy sculpins with the intake structures (Dorr and Miller 1975) suggests they may have subsequently been more vulnerable to impingement than other species.

During operational years, catches of sculpins have been more nearly like those of 1973 (before the riprap was completely in place). In addition, catches among operational years did not differ significantly by area. Because catches during operational years have fluctuated synchronously at Cook and Warren Dunes areas (Fig. 115), increased sculpin catches in 1979 appear to reflect a natural population fluctuation rather than an effect of Unit 2 operation.

Biological Data--

During April and May most slimy sculpins were in spawning condition (Table 72). This period coincides with the largest catches of sculpins by standard series fishing every year (Fig. 116). Because residence inshore accompanies the spawning season, sculpins become more vulnerable to our gear.

Table 71. Results of the Kruskal-Wallis test (nonparametric ANOVA) applied to 1973-1979 slimy sculpin trawl catch data from Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df	H statistic	Attained significance
Station (G, H, C, D, R)	4	10.3470	0.0350*
Area (Warren Dunes, south Cook, north Cook)	2	6.0495	0.0486*
(Warren Dunes, Cook Plant)	1	2.6493	0.1036
Year (1973-1979)	6	32.6210	0.0000*
(1973-74, 1975-79)	1	12.5220	0.0004*
(1973-74, 1975-78, 1979)	2	15.8240	0.0004*
(1973-74, 1975-77, 1978-79)	2	12.8930	0.0016*
(1973-74, 1975-77, 1978, 1979)	3	20.8420	0.0001*
Replicate (1st haul, 2nd haul)	1	0.2282	0.6328
Depth (6 m, 9 m)	1	4.7782	0.0288*
Time (day, night)	1	50.5820	0.0000*

* Significant (P <0.1).

Slimy sculpins did spawn in the study area because larvae were collected most years, and divers found sculpin eggs on the riprap (Dorr and Jude 1980). After June, sculpin catches became more sporadic as most adults returned to deeper waters. Wells (1968) also observed that sculpins abandoned shallow areas during summer and fall. However, at Cook stations during preoperational years a local population remained, despite the presence of warmer water than slimy sculpins normally select (Jude et al. 1979). As previously described, riprap in this area apparently provided a preferred habitat for these fish. During operational years, this local population was reduced either through impingement, avoidance of the plume, or natural factors.

Slimy sculpins were caught from the beach to 9 m every year. In trawls, there was only a slightly larger catch at 9- than at 6-m stations at Cook and Warren Dunes (Table 73). Eighty-five percent of the trawl catch occurred at

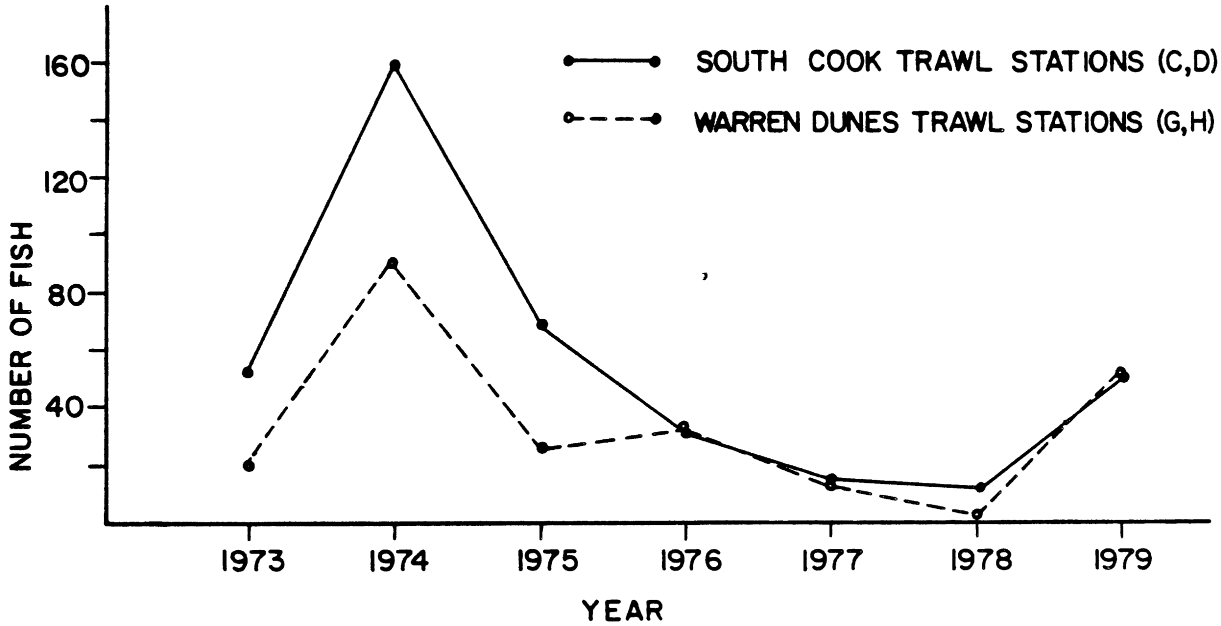

Fig. 115. Number of slimy sculpins caught by standard series trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

night. At beach stations, seining caught sculpins almost exclusively (98%) at night (Table 74), suggesting nocturnal activity and diel inshore movements are characteristic behaviors. Divers confirmed the increased activity of sculpins at night; they were seldom seen during the day (Dorr and Jude 1980).

The distribution of slimy sculpins has been found to be strongly influenced by temperature. Slimy sculpins are typically inhabitants of cooler areas in lakes and streams with rocky substrates (Scott and Crossman 1973). In southeastern Lake Michigan, Wells (1968) caught most sculpins in water from 4 to 6°C and Jude et al. (1980) rarely caught sculpins in water warmer than 15°C. Slimy sculpins caught in this study were also primarily in water temperatures less than 15°C. The highest catches were in temperatures from 4 to 7.9°C (Fig. 117), but large catches also occurred in warmer water (14 to 17.9°C). Those individuals caught in warmer water were generally less than

Table 72. Number of ripe and spent slimy sculpins caught by standard series trawling, gillnetting, and seining in Cook Plant study areas, southeastern Lake Michigan, 1973-1979. F = female, M = male, ND = no data.

Year	Sex	Gonad condi-tion	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	F	Ripe	0	16	1	0	0	0	0	0	0	0
		Spent	0	10	0	0	0	1	0	0	0	0
	M	Ripe	0	7	1	0	0	0	0	0	0	0
		Spent	0	1	2	1	0	0	1	0	0	0
1974	F	Ripe	1	92	3	0	0	0	0	0	0	0
		Spent	0	13	4	1	0	11	0	0	0	0
	M	Ripe	0	24	3	0	0	0	0	0	0	0
		Spent	0	1	1	0	1	2	0	0	0	0
1975	F	Ripe	0	24	13	1	0	0	0	0	0	0
		Spent	0	0	5	0	0	0	0	0	0	0
	M	Ripe	0	4	2	1	0	0	0	0	0	0
		Spent	0	0	1	0	0	0	0	0	0	0
1976	F	Ripe	0	17	0	0	0	0	0	0	0	ND
		Spent	0	19	0	0	0	0	0	0	0	ND
	M	Ripe	0	13	0	0	0	0	0	0	0	ND
		Spent	0	0	0	0	0	0	0	0	0	ND
1977	F	Ripe	0	6	0	0	0	0	0	0	0	0
		Spent	0	0	0	0	0	0	0	0	0	0
	M	Ripe	0	4	0	0	0	0	0	0	0	0
		Spent	0	0	0	0	0	0	0	0	0	0
1978	F	Ripe	ND	4	0	0	0	0	0	0	0	ND
		Spent	ND	0	2	0	0	0	0	0	0	ND
	M	Ripe	ND	0	1	0	0	0	0	0	0	ND
		Spent	ND	0	0	0	0	0	0	0	0	ND
1979	F	Ripe	ND	27	10	0	0	0	0	0	0	ND
		Spent	ND	6	1	1	0	0	0	0	0	ND
	M	Ripe	ND	25	1	0	0	0	0	0	0	ND
		Spent	ND	0	0	0	0	0	0	0	0	ND

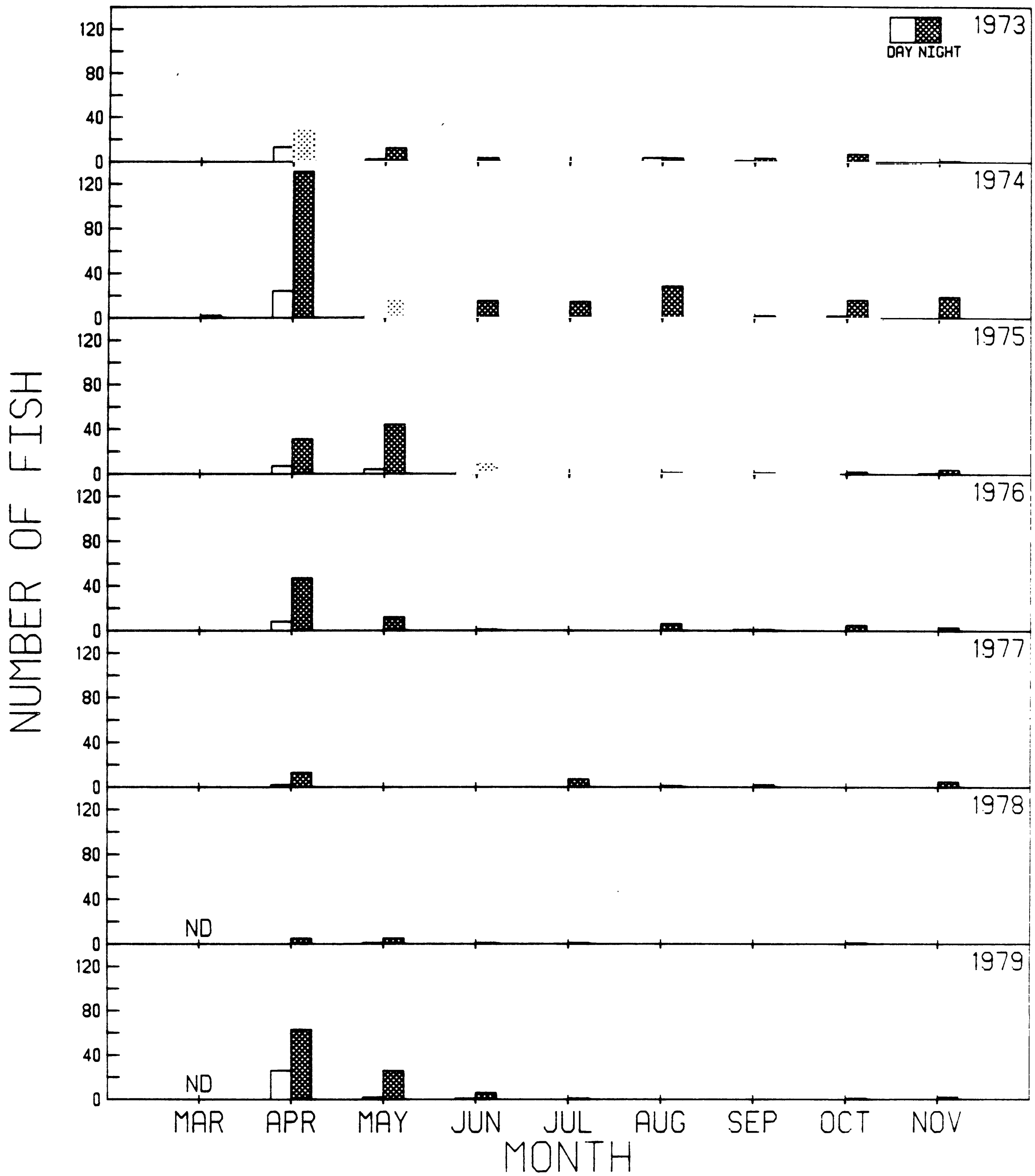

Fig. 116. Number of slimy sculpins caught by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years. ND = no data.

Table 73. Number of slimy sculpins trawled at standard series stations and station R in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years. ND = no data.

		6-m stations			9-m stations	
		Cook Plant				
		North	South	Warren Dunes	Cook Plant	Warren Dunes
Year	Time Period	R	C	G	D	H
1973	Day	ND	5	0	10	4
	Night	ND	21	4	15	12
1974	Day	ND	5	7	6	9
	Night	ND	92	36	55	38
1975	Day	2	3	1	10	2
	Night	41	25	9	30	13
1976	Day	1	1	1	4	1
	Night	18	11	8	15	22
1977	Day	0	0	0	2	0
	Night	1	2	2	9	11
1978	Day	0	0	0	0	1
	Night	4	4	0	8	1
1979	Day	5	4	2	13	10
	Night	18	16	22	17	17

34 mm in length (Fig. 118). Jude et al. (1980) observed this apparent relationship between length and temperature selection for another area in southeastern Lake Michigan but dismissed it as due to small sculpins being present only when the water is warm. We believe this is also the case in the Cook Plant vicinity. In addition, very few sculpins less than 35 mm were captured in standard series gear (Fig. 119). Hence, we cannot suggest that small individuals preferred warmer water. Large catches in the 14 to 17.9°C temperature range could be due to proportionally greater fishing effort at

Table 74. Number of slimy sculpins seined at standard series stations in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

		Cook Plant stations		Warren Dunes station
		North	South	
Year	Time Period	A	B	F
1973	Day	0	0	0
	Night	4	3	1
1974	Day	0	0	0
	Night	12	7	4
1975	Day	0	0	0
	Night	6	6	6
1976	Day	1	1	0
	Night	7	9	3
1977	Day	0	0	0
	Night	1	0	3
1978	Day	0	0	0
	Night	0	0	0
1979	Day	0	0	0
	Night	7	10	10

these temperatures and the previously described colonization of riprap at the Cook Plant intake and discharge structures (Jude et al. 1979).

Slimy sculpins were found infected with acanthocephalan parasites during all operational years. Incidence of parasitism at Cook stations increased from 17% in 1975 to 63% in 1979. The occurrence of parasitized sculpins at Warren Dunes stations was generally lower than at Cook. Small sample sizes during most years prevented determination of whether these differences were significant. However, at both Cook and Warren Dunes areas, the frequency of occurrence of this parasite in sculpins was lower than reported for another area in eastern Lake Michigan (Heufelder and Schneeberger 1980). Differences we observed may be

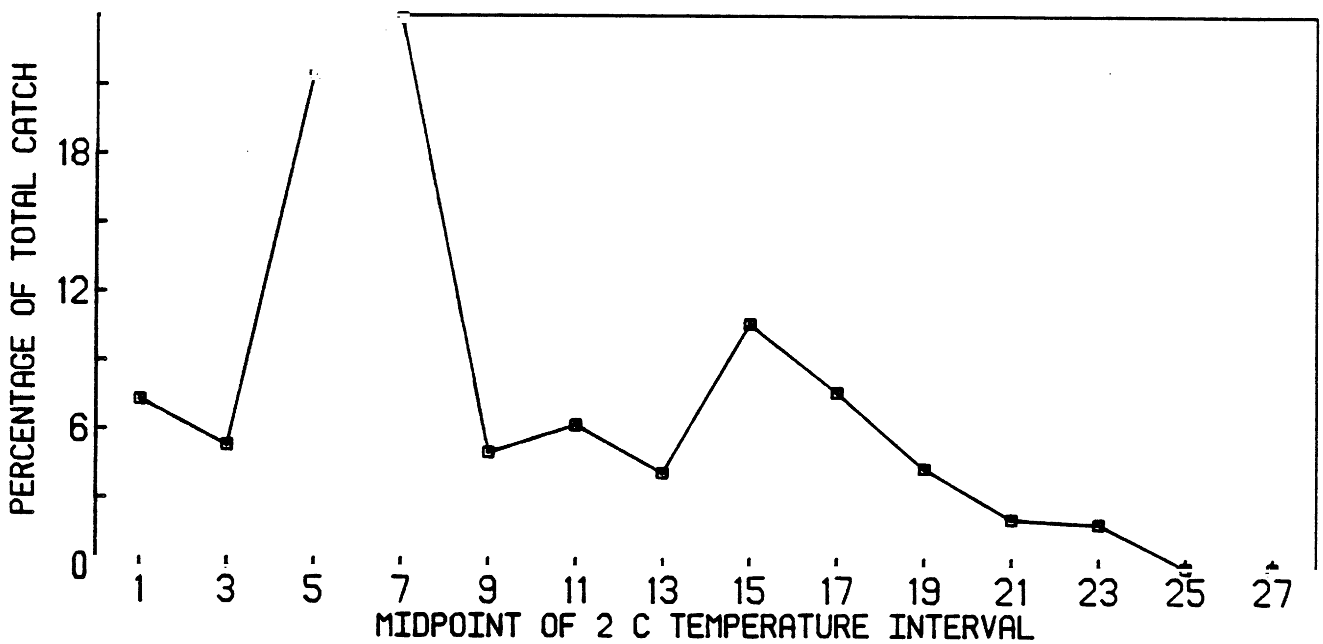

Fig. 117. Percentage of the combined total standard series catch of slimy sculpins collected during 1973-1979 from various temperatures in Cook Plant study areas, southeastern Lake Michigan.

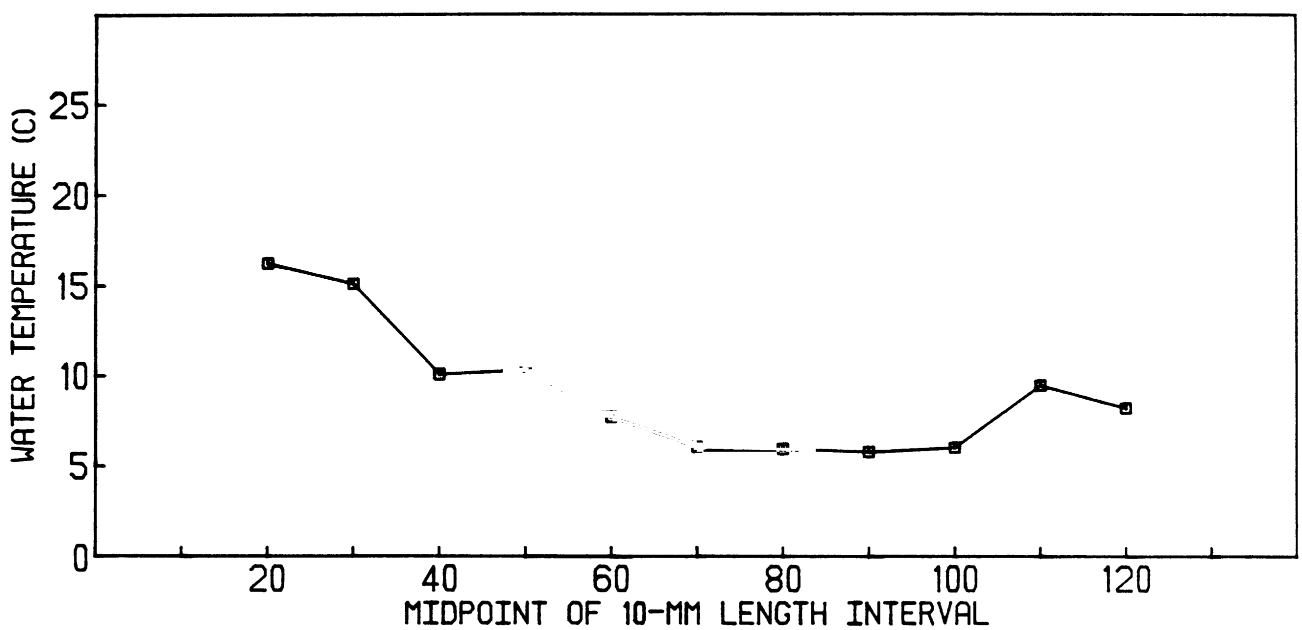

Fig. 118. Mean temperature at which various sizes of slimy sculpins were caught during 1973-1979 by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan.

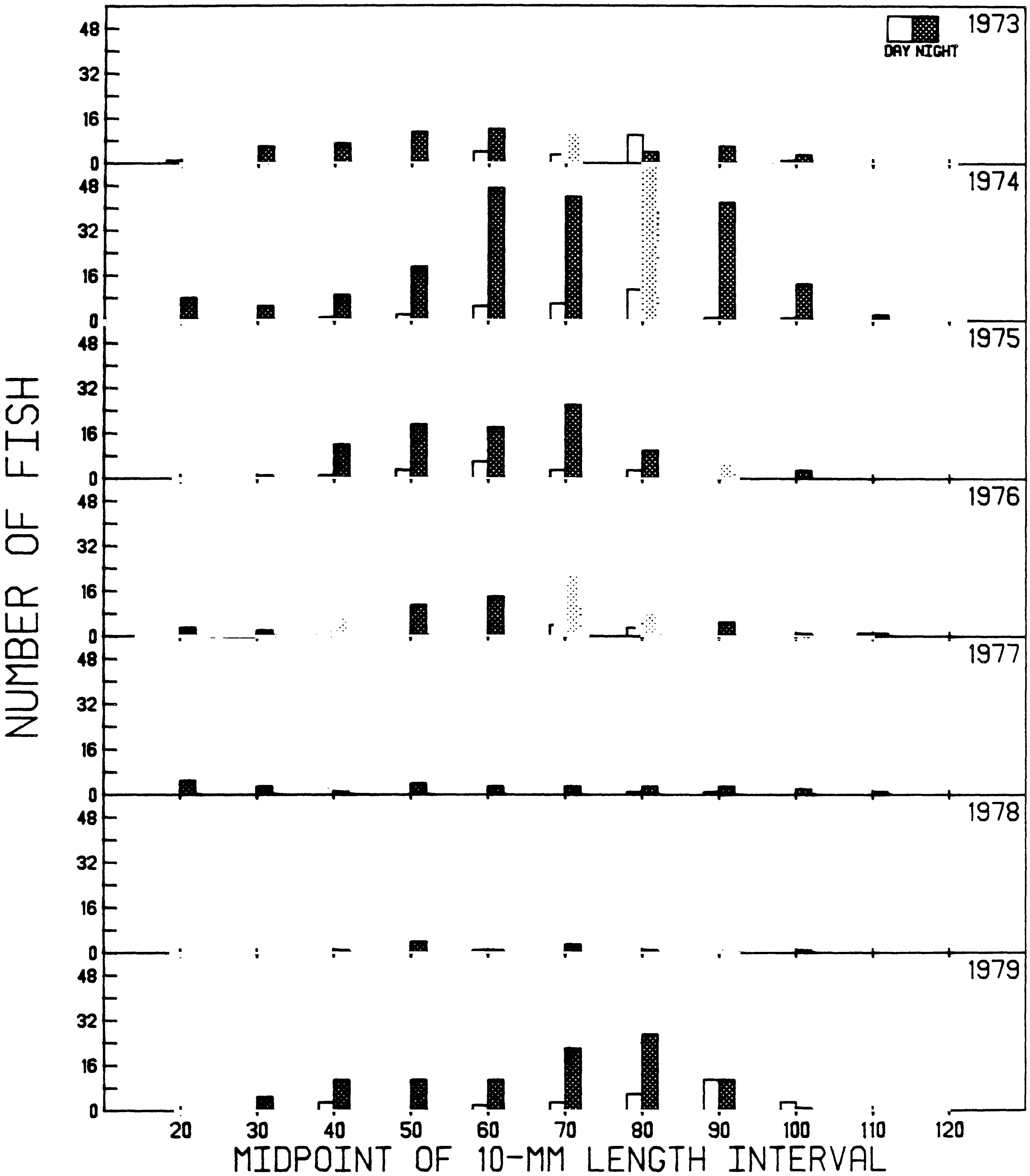

Fig. 119. Number of slimy sculpins caught by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

related to mode of transmission of the parasite, e.g., presence of the invertebrate food items in higher abundance on the Cook Plant riprap.

White Sucker

Operational Effects--

From 1973 to 1979, white sucker catches averaged 133 fish per year. Yearly catches ranged from a low of 86 fish in 1975 and in 1976 to a high of 188 fish in 1979. Catch from gill nets, the most effective gear, averaged 102 fish per year, while seines and trawls yielded averages of 27 and 8 fish per year, respectively.

The Kruskal-Wallis test applied to gill net data (seine and trawl catches were too small and sporadic to test statistically) showed significant differences among or between station, area, and year catches (Table 75). These results, however, did not establish any effects which could be attributed to plant operation. Multiple range testing of all years showed only the small catch in 1975 was significantly different from the high 1979 catch; during all other years catches were not significantly different from each other. Examination of area catches showed that, while catches were significantly larger at Warren Dunes stations in operational years, this area difference was also significant in preoperational years. Total gill net catches at each station also showed that more suckers were caught at Warren Dunes stations (Table 76).

No definite cause could be established for either an attraction to the Warren Dunes area or a repulsion from the Cook area. Other investigations at power plants on Lake Michigan have also shown white suckers in greater numbers

Table 75. Results of the Kruskal-Wallis test (nonparametric ANOVA) applied to 1973-1979 white sucker gill net catch data from Cook Plant study areas, southeastern Lake Michigan.

Source of variation	df	H statistic	Attained significance
Station (G, H, C, D, R, Q)	5	23.7990	0.0002*
Area (Warren Dunes, south			
Cook, north Cook)	2	16.4700	0.0003*
(Warren Dunes, Cook Plant)	1	16.2580	0.0001*
Year (1973-1979)	6	15.4190	0.0172*
(1973-74, 1975-79)	1	2.7880	0.0950*
(1973-74, 1975-78, 1979)	2	9.4220	0.0090*
(1973-74, 1975-77, 1978-79)	2	14.7970	0.0006*
(1973-74, 1975-77, 1978, 1979)	3	9.6665	0.0216*
Depth (6 m, 9 m)	1	7.2577	0.0071*
Time (day, night)	1	70.5320	0.0000*

* Significant ($P < 0.1$).

at control sites than at plant sites (Limnetics 1975, Brazo and Liston 1979, Jude et al. 1981). Postulations for this difference have ranged from avoidance of currents generated by power plant discharges to preference for control sites because some sites either had substrates with more sand or were closer to streams than the plant site. However, our findings and those of Brazo and Liston (1979) show white suckers preferring reference sites before plant operation, although both preoperational studies occurred during plant construction. We presume that a combination of factors may be influencing this species to avoid the power plant sites. The total disturbance at the plant site before plant operation which was caused by construction, i.e., dredging and resultant higher turbidity, and by currents generated by the discharge during plant operation, may be repelling these fish.

Table 76. Number of white suckers gillnetted at standard series stations and stations R and Q in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years. ND = no data.

		6-m stations			9-m stations		
		Cook Plant		Warren Dunes	Cook Plant		Warren Dunes
		North	South		North	South	
Year	Time Period	R	C	G	Q	D	H
1973	Day	ND	7	18	ND	3	13
	Night	ND	12	48	ND	7	25
1974	Day	ND	1	9	ND	3	10
	Night	ND	27	38	ND	5	20
1975	Day	1	0	0	2	1	0
	Night	8	17	36	9	9	18
1976	Day	5	4	5	1	2	13
	Night	7	10	16	9	7	8
1977	Day	0	1	5	1	1	4
	Night	16	13	62	7	13	21
1978	Day	3	6	2	4	4	5
	Night	13	18	28	5	10	11
1979	Day	3	7	4	0	5	19
	Night	12	23	22	9	18	22

Biological Data--

White suckers were captured year-round in the study area, with low abundance in winter and spring and a slight peak occasionally occurring in fall (Fig. 120). Apparently during winter many fish moved to water deeper than 9 m; and during spring, adults moved away from the study area to spawn in streams and rivers. Four sucker mesolarvae (species undetermined) were collected in the study area during May 1978, but we presume that they were river-spawned fish which moved into the lake. White suckers spawned in April

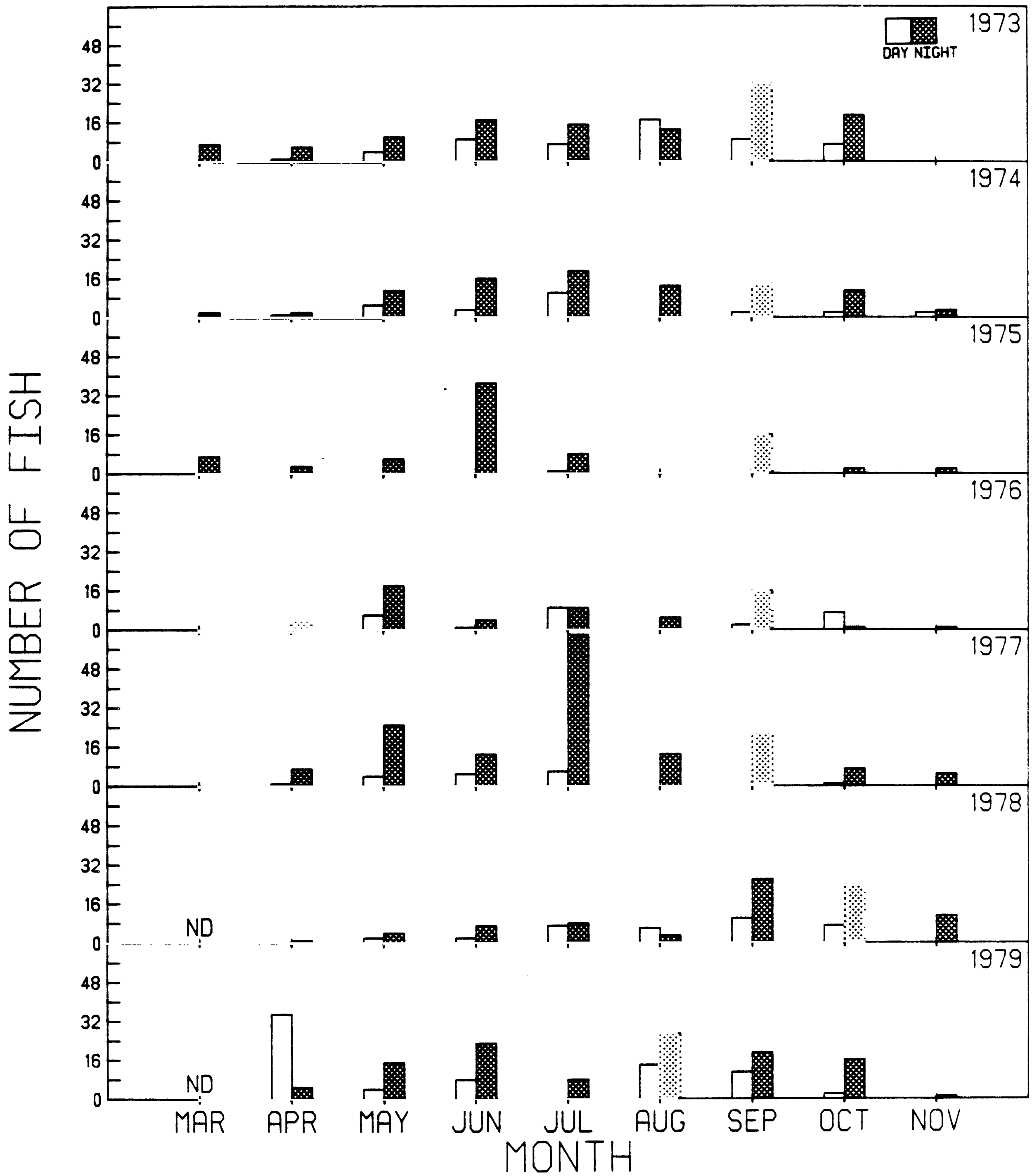

Fig. 120. Number of white suckers caught by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years. ND = no data.

and May with spawning possibly extending into March or June during some years (Table 77).

Larger night catches than day catches probably resulted from white suckers moving inshore at night (Fig. 120), although daytime net avoidance may have contributed to the difference. Nocturnal inshore movement was especially characteristic of larger fish (Fig. 121). Juveniles tended to be in the shallow beach zone both day and night, but were rarely caught at 6 and 9 m. Catches showed adults in low abundance during the day, usually evenly distributed at 6 and 9 m, but rarely present in the beach zone. At night adults moved inshore, occasionally to the beach zone, and were more abundant than during the day, especially at 6 m. White suckers in lakes do move shoreward at night to feed (Emery 1973, Scott and Crossman 1973).

Most white suckers collected were adults (Fig. 121). In contrast to the Ludington, Michigan, area where few white suckers over 500 mm in length were collected (Brazo and Liston 1979), we collected many fish over 500 mm. This regional difference may be related to the lack of exploitation in the southern end of the lake and possibly to better growth in our study area.

Young-of-the-year white suckers, usually collected in summer and fall in low numbers, were typically at modal lengths of 50-60 mm in July, but occasionally at 70-80 mm. By October-December, YOY had grown to modal lengths of 120-130 mm, although in some years YOY grew to 140-150 mm in length. Yearlings, some as small as 56 mm in spring, were rarely collected. These data reveal that YOY growth in Lake Michigan was extremely variable within and between years.

Table 77. Number of ripe or spent white suckers caught by standard series trawling, gillnetting, and seining in Cook Plant study areas, southeastern Lake Michigan, 1973-1979. F = female, M = male, ND = no data.

Year	Sex	Gonad condition	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	F	Ripe	4	1	0	0	0	0	0	6	0	0
		Spent	0	4	6	13	8	3	0	0	0	0
	M	Ripe	3	0	1	0	0	0	11	1	0	0
		Spent	0	0	1	2	6	1	4	3	0	0
1974	F	Ripe	0	0	2	2	0	0	0	2	1	3
		Spent	0	1	8	5	15	1	0	1	0	0
	M	Ripe	0	0	0	0	0	0	0	1	2	1
		Spent	0	1	2	0	3	0	0	0	0	0
1975	F	Ripe	5	1	0	1	0	0	0	0	1	2
		Spent	0	0	0	15	6	0	0	0	0	0
	M	Ripe	0	0	0	2	0	0	0	0	0	0
		Spent	0	0	0	19	2	0	0	0	0	0
1976	F	Ripe	0	1	9	0	2	0	3	2	1	ND
		Spent	0	0	4	1	1	0	0	0	0	ND
	M	Ripe	0	0	1	0	0	0	5	1	0	ND
		Spent	0	1	2	0	1	0	0	0	0	ND
1977	F	Ripe	0	1	1	0	5	0	7	1	2	1
		Spent	0	2	14	0	7	0	0	0	0	0
	M	Ripe	0	2	1	0	1	0	10	0	1	0
		Spent	0	2	7	0	4	0	0	0	0	0
1978	F	Ripe	ND	0	2	1	0	0	0	1	2	ND
		Spent	ND	0	1	0	0	0	0	0	0	ND
	M	Ripe	ND	1	0	0	0	0	4	6	2	ND
		Spent	ND	0	0	0	0	0	0	0	0	ND
1979	F	Ripe	ND	18	3	0	0	4	0	4	1	ND
		Spent	ND	0	8	1	0	0	0	0	0	ND
	M	Ripe	ND	6	0	0	0	0	1	0	0	ND
		Spent	ND	0	0	0	0	4	0	0	0	ND

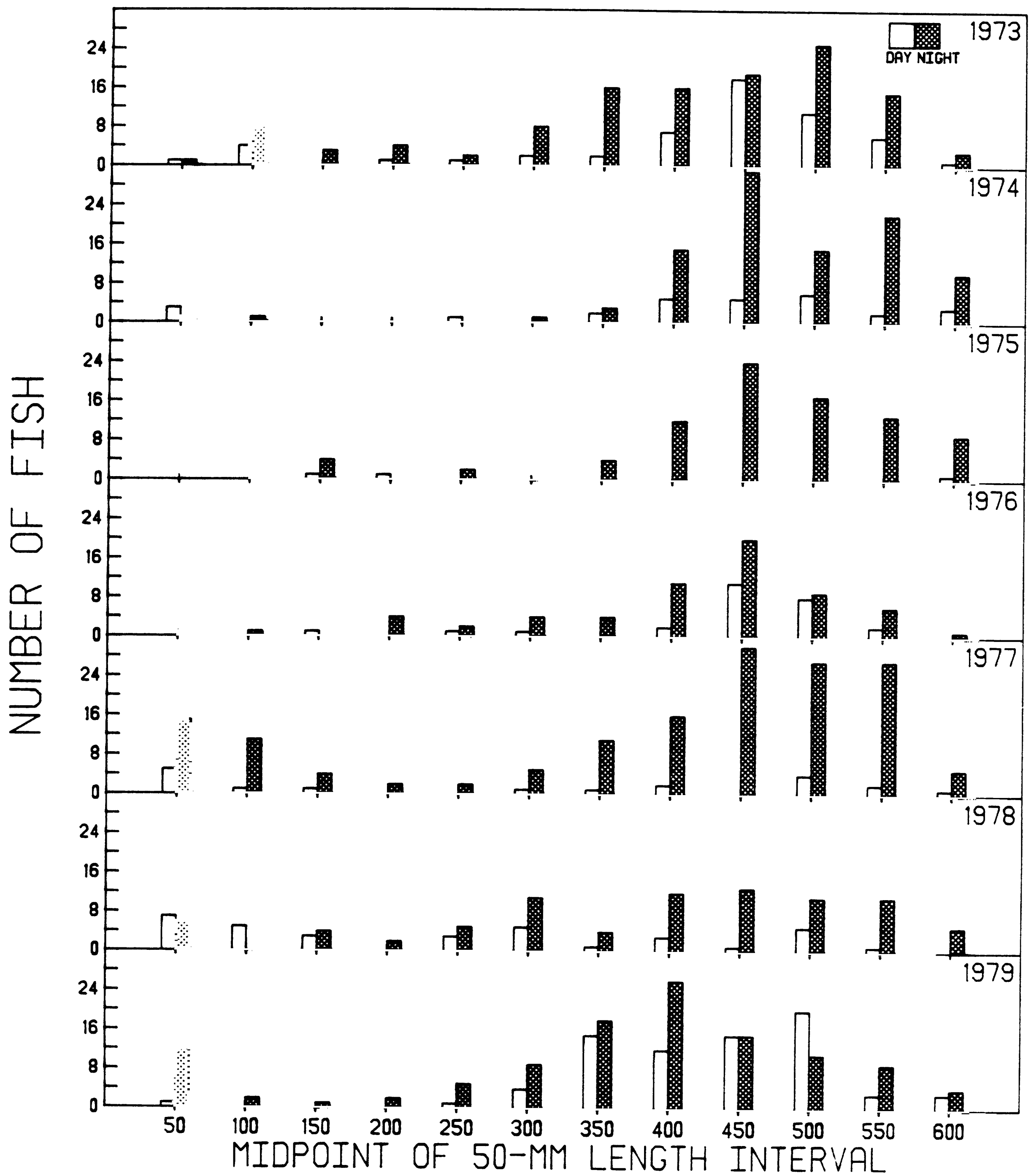

Fig. 121. Length-frequency histograms of white suckers caught by standard series gillnetting, trawling, and seining in Cook Plant study areas, southeastern Lake Michigan; 1973 and 1974 were preoperational years and 1975-1979 were operational years.

White suckers were collected over a wide temperature range (Fig. 122), probably indicative of their year-round presence in the study area. Smaller fish tended to be caught at higher temperatures than larger fish (Fig. 123), presumably because younger fish prefer warmer water than older fish.

Neoplastic lesions on the lips and heads of white suckers, first noted in 1974 (Jude et al. 1979), were also found in operational years. No changes or trends in numbers of suckers inflicted with the lesions were evident. Yearly numbers of fish inflicted varied from one fish in 1976 and in 1979 to eight fish in 1977. As in preoperational years, all of these fish were large adults and were caught at both the Cook Plant and at Warren Dunes. Brazo and Liston (1979) also noted that a very low percentage of white suckers collected from Lake Michigan near Ludington, Michigan, had papillomas on the head and anterior portion of the body.

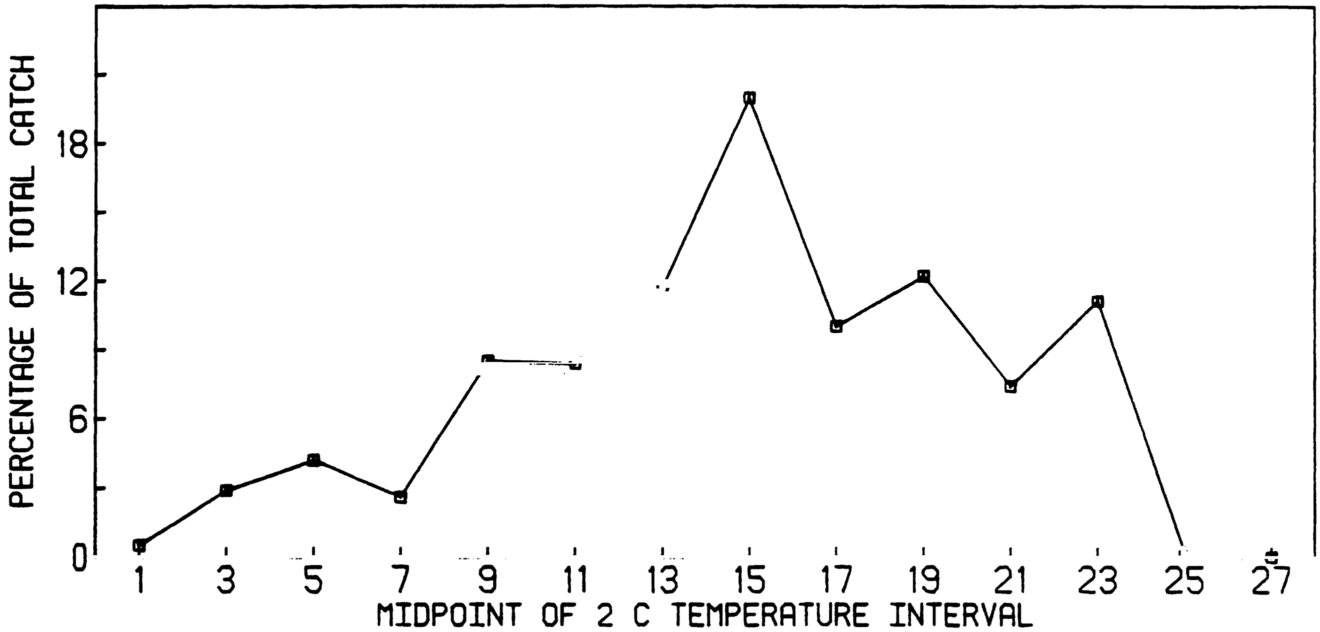

Fig. 122. Percentage of the combined total standard series catch of white suckers collected during 1973-1979 from various temperatures in Cook Plant study areas, southeastern Lake Michigan.

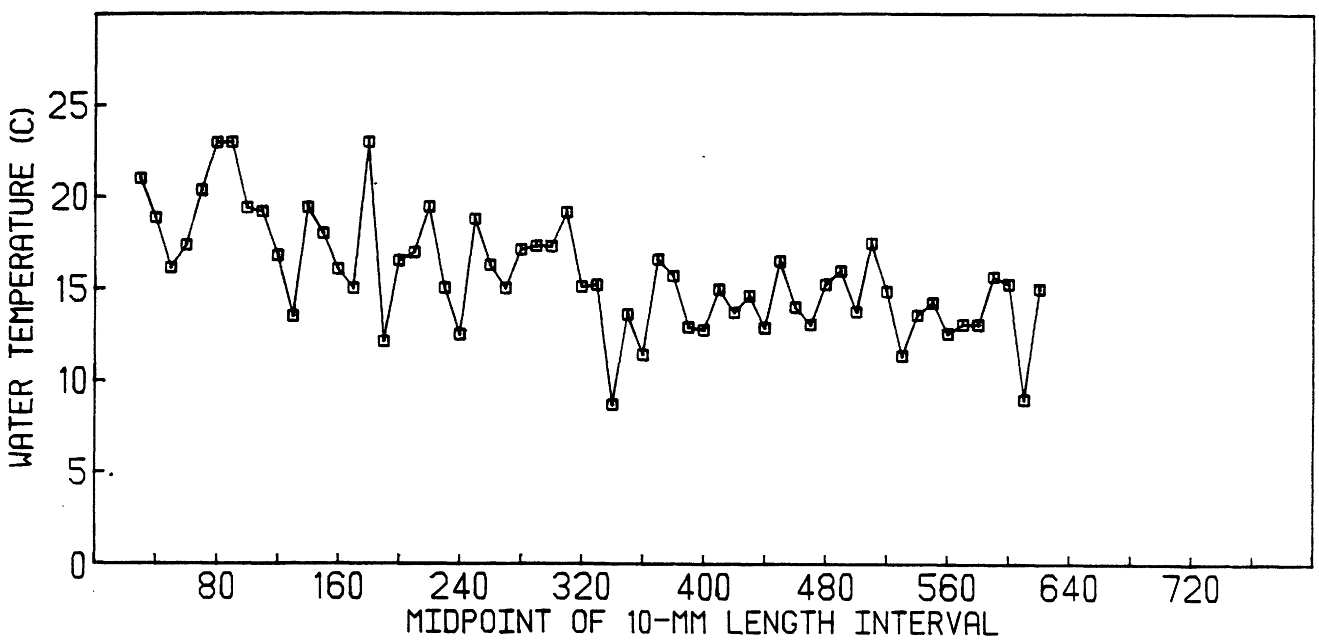

Fig. 123. Mean temperature at which various sizes of white suckers were caught during 1973-1979 by standard series gillnetting, seining, and trawling in Cook Plant study areas, southeastern Lake Michigan.

RARE SPECIES

Thirty-three species of fish were classified as rare in the study areas (<50 fish caught during any year). Seven of these species were collected during 6 or 7 of the study years (Table 78). Data for rare species could not be analyzed statistically because of small, sporadic catches (Appendices 4-7). However, catch data were examined for any substantial differences between preoperational and operational years and between study areas in operational years.

Catches of bluegill, burbot, channel catfish, ninespine stickleback, and sand shiner showed no trends or major differences which could be attributed to plant operation. Some rare species did exhibit differences in catch between the two study areas. Of 113 emerald shiners collected, 27 were caught at north Cook station A, 76 at south Cook station B, and only 10 at Warren Dunes station F. Because catches in preoperational years were larger in the Cook area than at Warren Dunes, plant effects were not considered as a cause for this difference. Although only 26 lake whitefish were collected, only 8 fish were collected in the Cook area. Smaller catches at Cook occurred in both preoperational and operational years, thus this difference did not appear to be a plant effect. Three species of redhorses were collected in greater numbers in the Cook study area. Of 37 redhorses collected, only 7 were captured at Warren Dunes. Additionally, redhorses were not collected in preoperational years. These findings indicate a possible attraction of redhorse species to the plant area, possibly caused by the plant's discharge.

Table 78. The number of years during 1973-1979 in which various rare species were collected at least once during standard series netting in Cook Plant study areas, southeastern Lake Michigan.

Species	No. yr in which species was caught	Species	No. yr in which species was caught
Burbot	7	Shorthead redhorse	3
Channel catfish	7	Black bullhead	2
Ninespeine stickleback	7	Brook silversides	2
Bluegill	6	Golden redhorse	2
Emerald shiner	6	Green sunfish	2
Lake whitefish	6	Rock bass	2
Sand shiner	6	Spotfin shiner	2
Golden shiner	5	Black crappie	1
Northern pike	5	Central mudminnow	1
Silver redhorse	5	Freshwater drum	1
Lake sturgeon	4	Lake chub	1
Largemouth bass	4	Logperch	1
Quillback	4	Pumpkinseed	1
Bluntnose minnow	3	Round whitefish	1
Fathead minnow	3	Smallmouth bass	1
Lake herring	3	Walleye*	1
Mottled sculpin	3		

* Gillnetted at 6-m north Cook station R, but not by standard series netting.

SUMMARY

This report details our analyses of field catches of juvenile and adult fish inhabiting the environment around the D. C. Cook Nuclear Power Plant. We seined, trawled, and gillnetted fish once a month, day and night, from April through November, 1973-1979. Our main emphasis was to determine whether statistically significant differences in catch between the plant and reference transects were the result of the power plant. Data are also presented on the biology of each species including growth, abundance, temperature-catch relationships, parasites, food eaten, and relationships with other species.

ABUNDANT SPECIES

Alewife was generally the most abundant fish collected over the course of the study, 1973-1979. The ANOVA of trawl, gill net, and seine catches showed that the plant had no significant impact on alewives in the plant vicinity. Significant main effects and interactions were attributed to biological and environmental factors unrelated to plant operation. For example, year was significant for all three gear types, but this was presumably due to alewife lake-wide population fluctuations. Higher preoperational than operational catches were also due to lake-wide declines in alewife populations. Catches were higher during one-unit operation than during two-unit operation when 1978 data were included in two-unit operation. The significance was due mainly to unusually low catches in 1978 and high catches in 1976. No Area effect was observed, but there was a significant effect of Station, which we felt was not related to plant operation. From 62 to 97% of the alewife catches were YOY. They were recruited to our gear in July-August and migrated offshore in

October and November. Growth rates in the first month of life were 0.64 to 0.79 mm/day. Yearlings generally lived offshore, but some returned to nearshore areas in the spring. Adults were most abundant in the study area during April-June. Annual catches of alewives generally declined over the period 1973-1979. Most alewives were collected at temperatures of 11-23°C. YOY were collected at higher temperatures than adults.

Bloaters were relatively uncommon in 1973-1974 catches, but increased substantially in 1978 and 1979. Most were caught in trawls. Only trawl data were amenable to statistical treatment and results demonstrated no differences in catches between areas that could be attributed to plant effects. We first collected YOY in September. Most yearlings and adults were obtained during summer upwellings. Young-of-the-year grew at a rate of about 0.65 mm/day in July. Yearlings were at modal lengths of 90-100 mm in spring and 120-130 mm in July-August. Very few adults (290) were collected. Most bloaters were collected at temperatures of 6-19.9°C.

Rainbow smelt was the third most abundant species in our catches. ANOVA applied to seine, trawl, and gill net catch data failed to demonstrate any changes in smelt populations that were related to plant operation. The few changes noted were attributable to natural population changes, coincidence of sampling with spawning or upwellings, or a consistent preference for one area over the other. Rainbow smelt were usually recruited to our gear in July-August at mean lengths of 28-41 mm. Growth rates through October were 0.28 mm/day. Yearlings were 63-72 mm in April; growth was 0.10 mm/day from April to June, then 0.39 mm/day through August. Adults were usually caught during the spawning season in April-May and during upwellings. Over 90% of

the fish were mature by their second year (132 mm). Smelt were caught primarily at 6-16°C, with YOY most often in 15-17°C water, yearlings in 10-13°C, and adults in <10°C water.

Spottail shiners were the second-most often collected fish, comprising from 9 to 40% of total catches. ANOVA of spottail catches showed several interactions which were explainable by year-class variability, seasonal changes in behavior and distribution, and gear selectivity. No plant impacts were apparent. Spottail shiner YOY were recruited in July-September. Growth rates were generally around 0.2 mm/day. Yearling growth rates fluctuated from 0.19 to 0.47 mm/day. Males and females matured by about 87 mm TL. Some spottails were afflicted by a myxosporidian parasite, which was most prevalent in peak spawning months of June and July. Most spottails were caught at 23°C.

Most trout-perch were caught in trawls. They were seldom seined in the beach zone. They usually ranked fifth in abundance among species collected. ANOVA of the trout-perch catch data showed many interactions due to varying vulnerability to our three gear types, variable year-class strength, patchy distribution, and responses to upwelling and other environmental factors. No catch differences were attributable to plant operation. Trout-perch YOY first appeared in August or September at lengths from 17 to 33 mm, a reflection of the prolonged (May-September) spawning season. Yearlings in April were 25-39 mm, with June to July growth rates ranging from 0.09 to 0.51 mm/day. From July to August, fish grew at rates of 0.44 to 0.70 mm/day. Most fish >80 mm were mature. Trout-perch were collected primarily in 14.6-20.5°C water. Fish exhibited a characteristic diel migration, moving inshore at night and offshore during the day. More (69%) fish were caught at night in all gear.

Yellow perch catches ranged from 1,576 fish in 1978 to 4,659 fish in 1979. Significant differences in trawl and seine catches were unrelated to plant operation. Gill net data revealed a tendency for greater perch abundance at the Cook Plant during both preoperational and operational years, which was attributed to perch being attracted to the riprap and discharges at the plant site. Yellow perch YOY were first collected in July or August; during fall perch moved offshore. Perch attained lengths between 60 and 105 mm (mean of 81 mm) during their first growing season. Growth rate varied between 0.6 to 0.9 mm/day during June to August. Yearlings were concentrated inshore in July and moved offshore by December. Mean length of yearlings in the fall was 123-171 mm (mean = 152 mm). Adults spawned from late May to June, and by October most had moved deeper than 9 m. Most fish (67%) were caught at temperatures between 18 and 24°C and smaller fish were caught in warmer water than adults.

COMMON AND RARE SPECIES

Brown trout were most often caught from spring to early summer in gill nets. They ranged from 120 to 770 mm in length, and most were caught in temperatures of 7 to 17°C. Though slight differences in catch between Cook and Warren Dunes were found, these differences were not related to plant operation.

Unusually large catches of chinook salmon during 1978 led to a significantly greater catch during operational years than preoperational years. However, no significant catch differences were observed between Cook Plant and Warren Dunes stations. Catches were largest in spring with adults predominating; juveniles were seined mostly during April-June. Fish caught ranged in

length from 60 to 980 mm. Most adults were taken in 5-17°C water, whereas juveniles (70-280 mm) were caught in 9-20°C water.

Most coho salmon were caught in seines and gill nets; catches were similar at Cook Plant and Warren Dunes. Coho ranged in length from 60 to 880 mm. About 75% of all coho were caught in 8-17°C water.

Annually, from 27 (1973) to 92 (1977) common carp were collected during the study. Total catches at Cook and Warren Dunes were nearly equal during preoperational years, but during operational years the carp catch at the Cook Plant increased dramatically. Statistically higher catches at Cook stations were attributed to attraction of common carp to the riprap, thermal plume, and its associated currents. Although spawning occurred at Cook stations, no discernible adverse impact of increased numbers of carp around the plant was detected. Carp were most often collected in 15-23°C water.

Most gizzard shad were collected in August-November. More were caught at Cook stations than Warren Dunes, which we attributed to an attraction to the discharged warm water at the plant. Gizzard shad collected were 70-720 mm and were found primarily in water 13-20°C.

Johnny darter catches ranged from 142 in 1975 to 423 in 1977. Some significant catch differences were observed but none established a detrimental plant effect. Darters were attracted to the Cook Plant riprap where they spawned. Adults and yearlings moved inshore in April and reached peak abundance in May-June when spawning occurred. More were caught at night than during the day. Most fish were 40 to 60 mm in length.

Catches of lake trout varied from 37 to 286 per year. Some differences in catch were noted but none could be attributed to plant operation. The slightly greater catch at Cook Plant stations may indicate an attraction

of lake trout to the plant's riprap for spawning in November. About 88% of the total catch occurred at night. Most fish occurred in 6 to 16°C water. Fourteen percent of the lake trout had lamprey scars or fresh wounds.

Most longnose dace were caught in seines, and larger catches were observed at south Cook beach station than at either of the other two stations. This larger catch was attributed to the presence of rocks and construction debris at the station. Most fish were caught in fall and at night. Fish were most often caught in 11 to 15°C temperatures.

Catches of longnose suckers averaged 82 fish/year, with gill nets the most effective gear. More longnose suckers were caught at Warren Dunes than Cook Plant stations in preoperational and operational years. This species apparently avoids the Cook Plant, presumably because of construction activities and discharge currents. Longnose suckers were year-round residents of the area except in April when spawning occurred, presumably in rivers and streams. Larger catches were made at night. In August, YOY were 90-110 mm. Neoplastic lesions were found on both longnose and white suckers.

More white suckers (about 133/year) than longnose suckers were collected. Like longnose suckers, white suckers preferred Warren Dunes stations over Cook Plant stations, but the difference was consistent over all years. White suckers spawned in spring, presumably in rivers, were most often caught at night, and YOY were 120-130 mm in the fall.

Rainbow trout catches ranged from 8 in 1974 to 86 in 1973. Catch differences were few and variable, suggesting no plant impact. Rainbows were 50 to 770 mm long and were most often caught in 5-17°C water.

Trawling accounted for 87% of the slimy sculpins we collected. In operational years, no significant differences between areas were noted. Sculpins

spawned in April-May on the Cook Plant riprap. A large proportion of the catch (85%) occurred at night. Sculpins were primarily caught in water <15°C; highest catches occurred at 4-7.9°C.

Another 33 species were collected and considered numerically rare in the study areas. Of these, five exhibited differences in catch between the two study areas. More emerald shiners were seined at the south Cook station, but this difference was also found before plant operation. More lake whitefish were collected at Warren Dunes (18 fish) than at Cook Plant (8) stations in both preoperational and operational years. More redhorses were collected at the Cook Plant (39) than at Warren Dunes (7), which is possibly a result of attraction of these species to the Cook Plant's discharge.

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